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Observations on the Plankton and Hydrographic Conditions of Aomori Bay during the Period 1933-1935.[1]

By

S. Kokubo and T. Tamura

The Asamushi Marine Biological Station, Asamushi, Aomori-ken

(With 4 Text-figures and 2 Tables)

This is the third report of our routine observations on the plankton and hydrographic conditions of Aomori Bay, for the years 1933–1935. The first and second report of this series covered the periods 1930–1931, and 1931–1932 respectively. While these two reports had some particular object in view such as the comparison of methods of collection, etc. the present report has no such aim, though the general line of the work is on a par with the two former studies. Associated with the former works the present will refer the reader not only to the general hydrobiological data, but also to the probable change in plankton and hydrographic conditions which may occur during such a prolonged period as six years or so.

The method employed in the present work was essentially the same as that in former investigations, the plankton being pumped with an ordinary wing pump and filtered through a small plankton net made of No. 25 bolting silk. The observations were made regularly twice a month at the routine station, though, according to weather, slight fluctuations were permitted. Thus sixty series of observations were made during three years (Table I, II). The factors of observation remained unchanged since the former investigations.

(1) Hydrographic Conditions

A) *Temperature of the sea*

Surface Temperature. The highest temperature of the year during the three years was 25.6°C observed on Aug. 21, 1933. In both

1) Contribution from the Asamushi Marine Biological Station, No. 144.

the other two years this temperature was 21.5°C. In the former study in 1930, however, a still higher temperature of 25.3°C was observed on Aug. 26.

The lowest temperature recorded during these three years was 5.0°C on March 11, 1933. In 1934 and 1935 the lowest temperatures were 5.8° and 6.4°C. The lowest temperature since 1930 was 4.8°C, observed on Feb. 28, 1931.

Vertical Distribution. As has been reported in the former investigation the physical and chemical conditions of sea water show distinct vertical distribution despite the fact that the depth of the station measured only thirty meters. This tendency is well shown by the distribution of the water temperature. From Table I and II it will be noted that the year is divided into two periods, the earlier one showing the period of indirect stratification, the later the period of direct stratification. The time and duration of these periods seems to vary from year to year. From 1930 until the present study the interval of these periods has been as follows.

Year	Indirect stratification	Direct stratification
1931	Jan. 10 to Apr. 14	May 1 to Sept. 16
1932	Oct. 16 to Apr. 16	May 17 to Aug. 19
1933	Oct. 31 to Mar. 11	May 3 to Sept. 15
1934	Oct. 7 to Feb. 18	Mar. 8 to Sept. 18
1935	Oct. 3 to Feb. 3	Mar. 4 to Aug. 18

From the above it can roughly be said that in Aomori Bay the indirect stratification ranges between October and March, and the direct stratification between April and September.

The difference in temperature between the surface and the bottom layer is not great and varies with the season. Generally the difference is greatest in summer and smallest in winter, hinting that the difference during direct stratification is greater than during indirect stratification. The maximum and minimum difference during the present and past observations may be tabulated as follows.

Year	Annual minimum	Annual maximum
1931	0.2°C (Feb. 28 etc.)	3.5°C (Sept. 1)
1932	0.3°C (Jan. 21)	4.0°C (Aug. 19)
1933	0.1°C (Nov. 16)	5.2°C (Aug. 1)
1934	0.1°C (Mar. 4)	3.3°C (Aug. 4)

From the above tables it will be noted that the seasonal change of the temperature of Aomori Bay is very similar to that of a fresh-water lake. In addition to both the summer and winter stagnation the presence of vertical circulation is also certain, though this circulation may differ from the spring or harvest circulation of the lake, which invariably shows the isotherm of 4.0°C.

B) Specific gravity of sea water

As has been stated since the previous investigations the first remarkable feature regarding the specific gravity is that the salinity of the water of Aomori Bay is relatively low when compared with the neighbouring open sea water. The second point worthy of note is that the salinity of the water of Aomori Bay is subject to a regular seasonal change. Thirdly it is also remarkable that a slight but steady tendency to vertical distribution is always observable, being most prominent in early spring each year.

Averaging all the observations (300 times) made during the present study the annual mean values for the years 1933–1935 were found to be 24.46, 24.47, and 24.53 respectively. Adding the data from our former study (Kokubo & Tamura, 1934) the annual mean since 1931 can be tabulated as follows.

Year	Annual mean	Fluctuation
1931	24.420	0.065
1932	24.552	0.067
1933	24.458	0.027
1934	24.467	0.018
1935	24.530	0.045
Mean	24.485	0.044

From the above it can be stated that the specific gravity varies around 24.49, the mean annual fluctuation being 0.044.

Over the observations of three years an extreme fluctuation of specific gravity was observed in 1933, giving the lowest value of 13.69 (surface) in early April, and the highest of 26.00 (bottom) in mid-July. This was the highest value since 1931, though a very close value of 25.89 was found in Dec. 1932.

In 1928 (Hatai & Kokubo) the seasonal change of the specific gravity was stated in regard to the surface water. In the present

study the seasonal change was studied by examining the mean value of five vertical layers, each of which was observed fifty nine times during the period 1933–1935. The result obtained by this means shows less fluctuation when compared with the result obtained only from the surface water. But the general tendency of seasonal change was almost the same as in the case of surface water. In the following table which was compiled from Table I and II the data for 1931–1932 were added from the previous paper (1934).

Month	1931	1932	1933	1934	1935
Jan.	—	24.85	24.22	24.97	24.62
Feb.	24.59	24.49	24.76	25.13	24.78
Mar.	—	24.66	24.65	25.20	24.74
Apr.	24.11	24.31	23.65	24.35	24.48
May	23.53	24.71	23.66	24.11	24.50
June	24.20	24.36	24.79	24.14	24.74
July	24.29	24.92	24.81	24.77	25.20
Aug.	24.85	24.15	24.91	24.00	24.77
Sept.	24.91	—	24.30	24.45	23.94
Oct.	24.67	24.64	24.64	24.08	24.53
Nov.	24.78	24.65	24.65	24.45	23.61
Dec.	24.64	24.25	24.57	24.42	24.11

(The monthly mean was obtained by averaging five vertical layers)

Looking through the above table it can be seen that, (1) at the beginning of each year the specific gravity shows a value a little higher than the mean (24.489), (2) this value decreases with the season and shows the minimum value in April (March–May), (3) from which time the specific gravity increases, attaining its maximum in July–August, (4) after this it again decreases until Sept.–Oct., (5) when it again rises and regains its initial value.

In explanation of the above seasonal change the prominent decrease of salinity in April might surely be caused by the thawing water which flows into Aomori Bay from inlet rivers. The subsequent increase until the maximum in July–August can be attributed to increased evaporation which condenses the sea water. A constant decrease following this maximum can be accounted for by decreased evaporation and an apparent increase from this time until the beginning of the year might be caused by the incomming warm current

which commences to prevail from October onwards. The last mentioned fact is demonstrated from the study of plankton organisms.

Vertical Distribution. As was stated in the former paper there is a regular vertical distribution showing an increase of salinity with depth. This tendency is exagerated seasonally with the decrease of the salinity of surface water. But that the above distribution is of a constant nature can be seen by looking through the Tables I and II.

The following table gives the specific gravity of each vertical layer which was averaged annually. From these figures it may be seen that the vertical gradient is not steep, yet the trend is highly constant. Moreover by comparing the specific gravity of the vertical layers for each year the fluctuation due to the year can also be seen (Fig. 1).

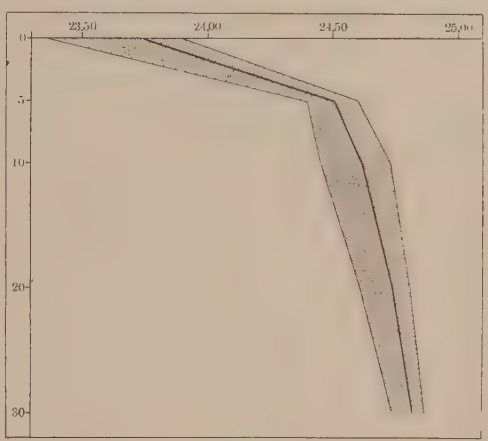

Fig. 1. Vertical distribution of the specific gravity of sea water, showing the range of fluctuation (dotted area) due to year. Thick line designates the average value of five years (1931–1935).
Abscissa—Specific gravity (23.50 = 1.2350)
Ordinate—Depth in meter.

As has been stated elsewhere the water temperature showed indirect stratification during the first half of the year, while the specific gravity showed direct stratification throughout the year. This means that the change in specific gravity due to temperature is negligible as compared with the actual difference of specific gravity which exists between surface and bottom.

Depth \ Year	1931	1932	1933	1934	1935	Mean
0 m.	23.90	23.82	23.36	23.65	23.95	23.74
5 m.	24.40	24.59	24.55	24.50	24.53	24.51
10 m.	24.45	24.69	24.73	24.64	24.57	24.62
20 m.	24.61	24.81	24.79	24.73	24.76	24.73
30 m.	24.74	24.85	24.87	24.82	24.83	24.82

C) *Dissolved oxygen*

During the present observation the O_2 content (per liter of sea water) varied between a maximum of 7.67 cc (100% sat.) (surface, Apr. 3, 1933) and a minimum of 3.76 cc (71.5% sat.) (bottom, Sept. 6, 1935), the mean value for all seasons and layers being 5.93 cc. The highest value exceeding 7.0 cc is often observed in the coldest season of the year, while the low value below 4.0 cc has been found very rarely. Probably such low value might be caused not only by decreased solubility of oxygen due to increased temperature but also by an occasional stagnancy of the stratification in that season.

According to 3 years' observation the presence of vertical distribution of O_2 content is ascertained. The annual average of each vertical layer during 1933–1935 is found to be as follows.

Year	0 m	5 m	10 m	20 m	30 m
1933	5.99	6.00	6.12	6.18	6.15
1934	5.77	5.86	5.86	5.82	5.66
1935	5.97	5.89	5.95	5.93	5.82
Mean	5.91	5.92	5.98	5.98	5.88

From the above table it can be seen that the content of O_2 increases from surface to intermediate layer and decreases again towards bottom. This tendency shows that the vertical distribution of O_2 has no direct correlation with depth, suggesting that the distribution of O_2 is not only influenced by physical or chemical factors but that it is also controlled by the biological factors. The lowest content which was always found in the bottom layer should be attributed to the respiration of bottom animals and the oxydation of organic deposit due to bacterial action.

To find the relation of seasonal change of O_2 content the five vertical layers were averaged. The value thus obtained can be tabulated in the following table.

This table shows that as a general rule the O_2 content attains its highest value in March or April, and becomes lowest in September. Comparing this seasonal change with that of water temperature (Fig. 2) it can be seen that the change of O_2 content may be largely caused by the change of water temperature.

Year / Month	1933		1934		1935		Mean	
	O_2 (cc)	Water temp.	O_2 (cc)	Water temp.	O_2 (cc)	Water temp.	O_2 (cc)	Water temp.
Jan.	6.57	7.8	5.54	8.2	6.29	9.1	6.13	8.4
Feb.	6.89	6.8	6.40	6.4	6.29	8.4	6.53	7.2
Mar.	7.11	5.4	6.62	6.9	7.07	7.1	6.93	6.5
Apr.	**7.14**	6.8	6.51	6.8	6.92	7.1	6.86	6.9
May	6.59	9.8	6.33	9.6	6.35	8.4	6.42	9.3
June	6.34	12.4	6.00	13.4	5.94	13.3	6.09	13.0
July	5.43	18.3	5.45	17.1	5.24	18.4	5.37	17.9
Aug.	4.90	23.2	4.74	18.5	5.38	20.5	5.01	20.7
Sept.	4.73	23.4	**4.59**	20.9	4.74	20.2	4.69	22.2
Oct.	4.83	19.9	4.74	19.0	4.82	19.4	4.80	19.4
Nov.	5.13	15.1	5.44	15.4	5.21	16.2	5.26	15.6
Dec.	5.12	13.0	6.33	10.0	5.86	11.8	5.77	11.6

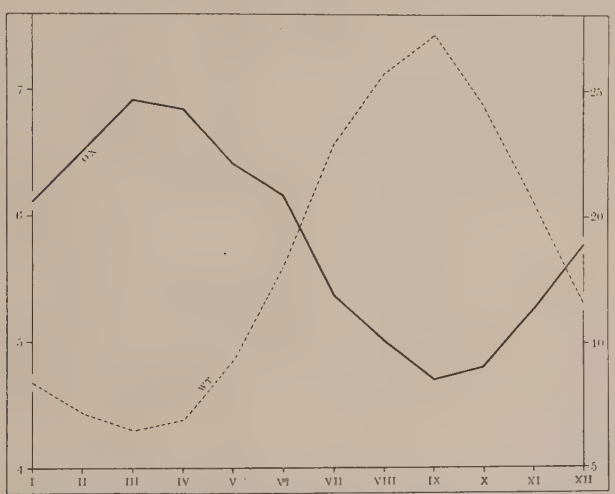

Fig. 2. Seasonal change of the O_2 content of sea water. Change of monthly average (through all depths) in the course of 1933–1935.

Thick line—Oxygen content (OX).
Dotted line—Temperature of sea water (WT).
Abscissa—Months.
Ordinate—left side, O_2 in cc (per L of water)
right side, temperature 0°C.

As expressed in terms of percentage saturation the range of oxygen during the present observation is as stated in the following table.

	Highest saturation (%)	Lowest saturation (%)
1931	110.9 (July 1)	76.2 (Sept. 1)
1932	105.3 (Mar. 20)	72.7 (Aug. 19)
1933	107.5 (July 5)	83.6 (July 16)
1934	104.1 (June 16)	70.4 (Oct. 16)
1935	107.3 (June 6)	71.1 (Oct. 2)

In the above table the data for 1931–1932 were added from our former work (1934). From this table it can be seen that the highest saturation since 1931 is 110.9% (1931), and the lowest is 70.4% (1934). RAKESTRAW's (1933) work which was done on the open waters of the Gulf of Maine shows that the maximum and the minimum saturation respectively ranged between 114% and 63%. These results seem to show that unless very deep waters or some special conditions are present the oxygen saturation varies around the above ranges. But examples showing wider changes are reported by several authors. MARSHALL & ORR (1930) found as high a saturation as 138% at Loch Striven. YOSHIMURA & others (1930) reported a high saturation of 139% from Aburatsubo. ITO (1930), studying on the open waters of the North Pacific, found that the extreme value of oxygen saturation has a maximum of 148% and a minimum of 16%, the latter value being found at a depth of 400 meters.

As was stated in a former work (KOKUBO & TAMURA, 1934) the over saturation of oxygen in Aomori Bay depends largely on the vegetation of plankton diatoms. In the present study, too, the general tendency that in the period when the diatoms flourish the saturation increases is observed. For instance in Table I and II it is plain that the high saturation around 100% was found in the period from Feb. 3 to Sept. 15 when the volume of diatomaceous plankton showed marked increase. Such a tendency was well observed in 1934 and also in 1935, especially in the collection of March 21, 1934 (No. 27), and Aug. 4, 1935 (No. 54) (Tables I and II). Slight discrepancy found between the oxygen saturation and volume of plankton can be accounted by zooplankton which affects the oxygen content.

D) pH of sea water

During the period of the present investigation the pH of water

ranged from 8.2 to 8.3, the annual fluctuation and annual mean being as follows.

Year	Max.	Min.	Mean
1933	8.30 (Mar. 11)	8.20 (Jan. 6 etc.)	8.22
1934	8.30 (Oct. 3 Nov. 1)	8.18 (May 2)	8.24
1935	8.30 (Aug. 1 etc.)	8.20 (Apr. 8 etc.)	8.25

As was formerly stated (Kokubo, 1932) the pH is a factor of biological significance, and is markedly influenced by the plankton condition. In the former (1932) as well as in the present study both factors show no strict coincidence. At the same time, however, it is also true that in all three years a rough parallelism between the pH and plankton volume is observable. This means that in Aomori Bay phytoplankton accounts for the bulk of plankton, for it is phytoplankton that raises the pH of sea water. The reason why the parallelism is not close may be considered as due to the change of the quantity of zooplankton which lowers the pH of water.

In order to see the seasonal change of pH the monthly average of each year was calculated from Tables I and II, and given as follows. In this table the monthly pH was obtained by averaging the pH of the five vertical layers.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1933	8.21	8.21	8.27	8.19	8.21	8.23	8.23	8.24	8.23	8.26	8.24	8.22
1934	8.24	8.23	8.23	8.22	8.21	8.23	8.21	8.26	8.27	8.26	8.26	8.23
1935	8.26	8.25	8.26	8.21	8.22	8.21	8.28	8.27	8.28	8.27	8.30	8.30
Mean	8.23	8.23	8.25	8.21	8.21	8.22	8.24	8.26	8.26	8.26	8.27	8.22

The above table shows that the pH was relatively low in the first half of the year, while markedly high in the latter half. This tendency was already stated in the previous paper (Kokubo, 1932) so that the present result well serves to prove the above tendency. Such tendency can be explained and accounted for by equilibrium between the photosynthesis of phytoplankton and the respiration of zooplankton. In the first half of the year the rise of pH due to diatom vegetation is hindered by the zooplankton which also increases during that season, while in the latter half of the year there is no remarkable increase in zooplankton, thus resulting in the rise of the pH of water. On the

other hand, however, it can not be overlooked that the seasonal change of the salinity of water might have also played a part in this connection, because the pH of water changes in proportion to the salinity of water, which is high in the first half and low in the latter half of the year.

Finally, fixing our attention on the vertical distribution of pH it can be seen, from Table I and II, that the pH of 30 m (bottom) is slightly lower than that in 20 m or upwards. Though this tendency is slight it deserves special attention, because of the fact that this low pH is caused by the oxydation of bottom organisms is well reflected by the oxygen content of the bottom layer.

E) Colour and transparency

In the former investigations of this series (1931) (1932) (1934) it was reported that the colour of the water of Aomori Bay as measured by FOREL's scale ranges between No. 3 and No. 9. The latter value is likely to have been the extreme value, having never been found since Nov. 28, 1929. Since 1929 the reading of FOREL's scale varied in the following range.

1929	No. 3—No. 9	1933	No. 3, 5—No. 5
1930	No. 3—No. 5	1934	No. 3 —No. 6
1931	No. 4—No. 6	1935	No. 3 —No. 6
1932	No. 4—No. 5		

From which it can be concluded that the annual change usually ranges between No. 3 and No. 6.

In 1934 (KOKUBO & TAMURA) it was stated that the reading of FOREL's scale does not strictly coincide with the quantity of plankton. But as will be stated later the volume of plankton and the reading of FOREL's scale show a reversed relation to the transparency of the water. Therefore, logically the change of the former two factors should coincide. And hence the discrepancies often found can be ascribed to the other factors which disturb this relation. Probably the contamination of water due to detritus or seston may be one of the main causes disturbing the above relation.

The transparency of the water was observed by using SECHEE's disk, 30 cm in diameter. The results were tabulated as follows. In this table, besides the result of the present investigation the author's previous data were added for the purpose of comparison.

Year	Range of transparency	Mean
1929	2.5—18.5	10.7
1930	7.0—25.0	14.0
1931	5.0—20.0	10.0
1932	7.5—14.0	11.4
1933	6.5—19.0	12.2
1934	6.5—25.0	12.2
1935	5.5—18.0	11.8

The above data show that during the present investigation (1933–35) the transparency varied between 5.5–25.0 meters. A low measure of 5.5 meters observed on Nov. 3, 1935 was much higher than the low value of 2.5 (Nov. 28, 1929) which seems to have been the lowest ever observed. throughout seven years the highest value of 25 meters was twice (Feb. 22, 1930 and Mar. 8, 1934) observed probably suggesting that this value may be taken as the

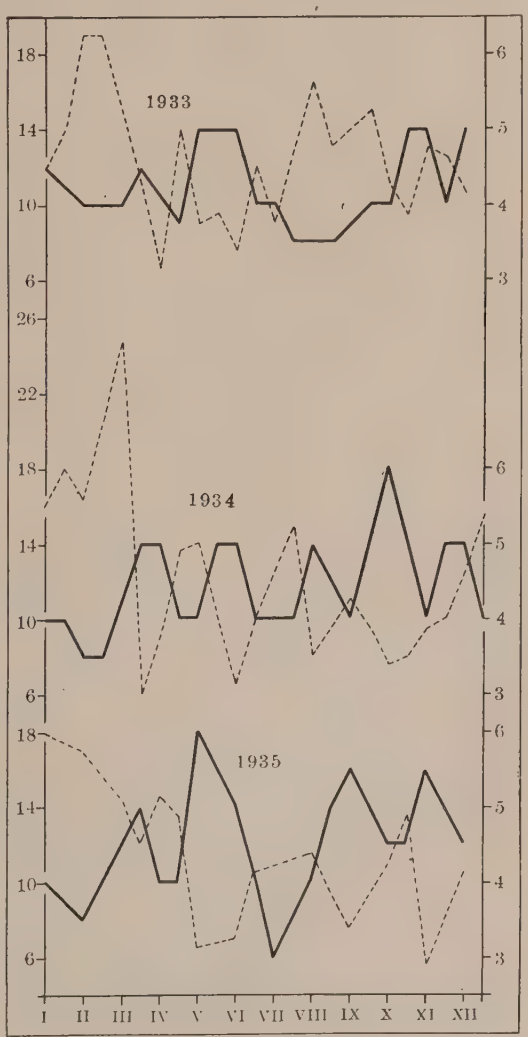

Fig. 3. Relation between the transparency and the colour of water.
Thick line—Reading of FOREL's scale.
Dotted line—Transparency in meter.
Abscissa—Months.
Ordinate—Left side, transparency in meter Right side, reading of FOREL's scale.

highest value observable in Aomori Bay.

In 1932 (KOKUBO) it was stated that there is a close relation showing reciprocal change between the transparency and the colour of water. Such a relation was likewise observed in the present investigation. Though this tendency is very steadily shown in each of the three years it is particularly accurate in 1935 (Fig. 3). Looking through the data of three years (1933–1935) it can also be seen that a change of more than 2 meters in transparency is apparently reflected by the change of one or more of the scale reading in FOREL's scale. Furthermore, from KOKUBO's (1932) and the present investigation it seems safe to state that the transparency is high at the beginning, and low at the end of the year.

As the transparency was considered in connection with the volume of plankton a rough reversed relation can be seen throughout the three years (Fig. 4). In connection with transparency POOL and ATKINS (1929) stated that the magnitude of transparency shows the depth where the light intensity decreased down to 16% of the intensity of water surface. If it were so the depth of 16% intensity in Aomori Bay ranges between 2.5 and 25 meters.

F) Quantity of the plankton

QUANTITY OF PLANKTON. During the period of the present investigation (1933–1935) the mean volume of plankton (as five vertical layers are averaged on each observation) per cubic meter of water ranged from the minimum of 11 cc (Oct. 7, 1933) to the maximum of 929 cc (May 18, 1934). Comparing these values with those of the former investigation (1931–1932), which were added to the following table, it can be seen that the maximum volume in 1932 (1672 cc) is greater by far than that in 1934 (929 cc).

	Annual maximum	Annual minimum	Annual mean
1931	653 cc (June 16)	16 cc (Jan. 19)	183 cc
1932	1672 cc (Mar. 10)	20 cc (Apr. 16)	284 cc
1933	859 cc (Apr. 3)	11 cc (Oct. 7)	225 cc
1934	929 cc (May 18)	25 cc (Mar. 8)	197 cc
1935	756 cc (Aug. 4)	32 cc (Dec. 1)	254 cc

The above results may be taken as showing that the plankton volume in 1932 was unusually great. This can also be seen by com-

paring the annual averages for five years which are given above. As will be seen in this table the annual mean in 1932 (284 cc) shows the greatest abundance of plankton in that year. Moreover the above table will show in what range the volume of the plankton of Aomori Bay varies.

In order to get an idea of the extreme abundance of plankton it is of interest to compare the maximum and the minimum through all depths and seasons. Throughout the five years 1931–1935 the maximum volume was found to be 1672 cc observed on Mar. 10, 1932 at a depth of five meters, the second greatest being the 1367 cc of the present period observed on Apr. 21, 1933. The minimum volume observed was 7 cc which was observed on May 31, 1931 at the surface, and on Feb. 3, 1934 likewise at the surface.

Seasonal Change. The mode of the seasonal change of plankton has been a special aim of the present series of investigations so that

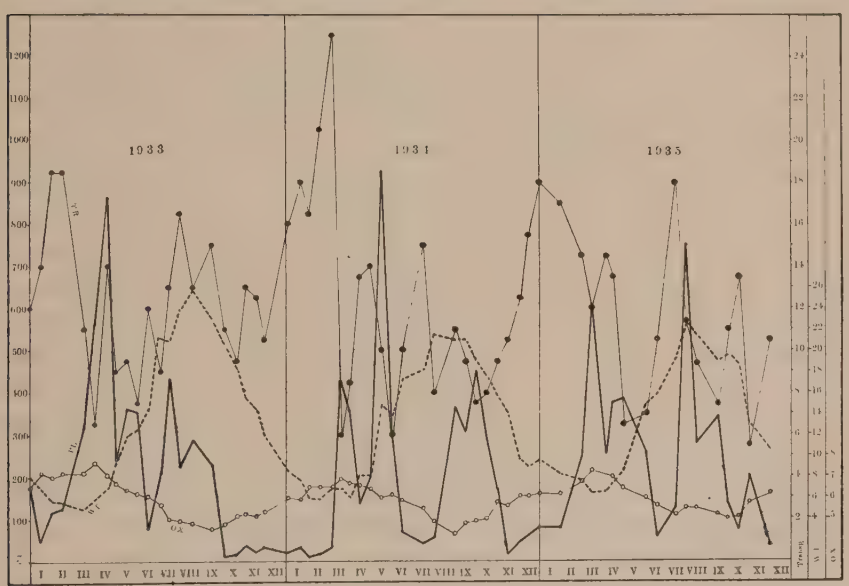

Fig. 4. Seasonal change of the volume of plankton (PL), the temperature of sea water (WT), transparency (TR), and oxygen content of sea water (OX), during 1933–1935.

Abscissa—Months

Ordinate—PL, volume of plankton in cc per litre of water.
Transp (TR), transparency in meter.
WT, temperature of sea water.
OX, oxygen content of sea water.

the data has been particularly examined from this angle. In the previous papers conclusions were tentatively made which were liable to alteration on securing further data. Therefore the addition of the present data was awaited before formulating a more established rule.

As is evident from Fig. 4 it can be accepted that in 1933 there were two periods of plankton increase, the one which occurred in April being by far greater than that which occurred in July. The first increase corresponds to the so-called vernal multiplication, whilst the latter is a summer increase. As can be generally expected the vernal increase of plankton in this case was due to the vegetation of diatoms. The summer increase, however, was also caused by the flourishing of diatoms such as *Chaetoceras, Rhizosolenia,* etc.

In 1934 three times of multiplication were found during the course of one year. The first increase which was found in March was representative vernal increase. The second increase which was found in May showed the greatest abundance of this year. This increase seems to be neither summer nor autumnal vegetation, probably being the occasional increase. The third increase which ranged from September to October was a representative autumnal vegetation, and was more pronounced than the vernal vegetation.

In 1935, too, three times of multiplication were observed. The vernal increase which occurred in March was very distinct and was followed by an subsequent vegetation, the second increase, which ranged from April to May. Third multiplication which showed the maximum increase of this year was found in August, showing that the summer multiplication occasionally culminates in the greatest abundance of the year.

The former investigation of this series (Kokubo & Tamura, 1932) led us to conclude that in Aomori Bay the vernal increase of diatoms is generally very marked and is regularly observed every year during the period from late-February to April. Following the vernal increase one or two increases of secondary vegetation occur by August, and finally give rise to the harvest vegetation which is mostly scanty as compared with vernal vegetation.

After looking through the data of the present investigation it was found that the above conclusion fairly fits the present result. It can, however, be concluded in addition that sometimes the autumnal vegetation is not found (as in 1935), and that during the winter no vegetation occurs. The latter conclusion may also be remarkable as there has

been found no sign of vegetation during winter throughout the whole period (1930–1935) of the present series of investigation.

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Tab

No. of exp.	Date of observation			Air temp. °C.	Water temp. °C.						O_2 c.c./L						Percent. saturation of O_2					
					O_m	5	10	20	30	(mean)	O_m	5	10	20	30	(mean)	O_m	5	10	20	30	O_m
			(a.m.)														%					
1	1933	Jan.	6. 9.10	3.0	8.0	8.1	8.2	8.3	8.3	8.20	6.45	6.45	6.40	6.39	6.30	6.44	96.5	97.0	96 6	96.5	95.4	24.2
2	»	»	17. 9.20	4.4	7.0	7.3	7.5	7.6	7.6	7.40	7.24	6.67	6.72	6.62	6.35	6.72	104.0	98.4	99.5	98.1	94.6	21.4
3	»	Feb.	3. 9.30	3.5	5.8	6.5	6.5	6.6	6.7	7.42	7.04	6.77	6.88	6.62	6.72	6.81	100.5	98.4	100.0	97.3	96 5	24.6
4	»	»	14. 10.00	−0.5	5.5	6.2	6.5	6.5	6.5	6.24	7.19	7.09	7.04	6.83	6.72	6.97	102.0	102.0	102.0	99.5	97.8	24.6
5	»	Mar.	11. 10.00	0.0	5.0	5.4	5.5	5.5	5.5	5.38	7.25	7.14	7.14	7.04	7.00	7.11	101.5	101.5	101.5	100.0	99.7	24.1
6	»	Apr.	3. 9.10	9.5	5.9	7.0	7.0	6.5	6 0	6.48	7.67	7.25	7.25	7.14	7.04	7.27	100.0	106.3	106.3	104.0	102.0	13.6
7	»	»	21. 9.50	11.0	7.3	7.3	7.0	7.0	7.0	7.12	7.14	7.04	7.04	6.95	6.77	6.99	105.1	104.0	104.0	102.5	100.0	24.5
8	»	May	2. 9.30	15.5	9.5	9.1	8.8	8.5	8.3	8.84	6.70	6.70	6.70	6.58	6.62	6.66	100.0	103.3	103.3	101.5	101.5	19.6
9	»	»	15. 10.00	14.5	11.7	11.0	10.6	10.1	10.0	10.70	6.35	6.55	6.50	6.60	6.60	6.52	100.0	104.2	102.6	103.5	103.5	20.8
10	»	June	1. 8.40	14.5	12.5	12.0	11.4	10.9	10.5	11.50	6.25	6.40	6.30	6.45	6.50	6.38	102.5	104.0	101.2	103.1	102.7	24.1
11	»	»	15. 9.00	14.2	14.5	13.6	13.5	12.3	12.0	13.20	6.10	6.30	6.45	6.40	6.20	6.29	104.0	107.2	109.1	106.1	102.0	24.3
12	»	July	5. 9.00	21.6	21.0	19.2	16.5	16.0	15.8	17.7	5.65	5.70	5.90	5.95	5.80	5.80	107.5	105.8	104.1	104.1	102.5	25.2
13	»	»	16. 10.00	23.8	20.8	19.8	19.5	18.0	15.8	18.8	5.04	5.19	5.14	5.25	4.66	5.06	95.5	98.1	96.3	96.3	83.6	24.1
14	»	Aug.	1. 9.15	25.6	23.8	23.1	22.8	21.8	21.2	22.5	4.94	4.99	4.91	4.88	4.87	4.92	98.4	98.0	96.8	94.5	93.2	24.4
15	»	»	21. 10.20	29.5	25.6	24.8	24.5	22.5	21.8	23.8	4.75	4.99	4.83	4.92	4.85	4.89	94.3	100.0	97.5	96.0	94.5	24.7
16	»	Sept.	15. 8.30	24.0	23.0	23.5	23.5	23.6	23.5	23.4	4.55	4.55	4.55	4.44	5.55	4.73	88.6	89.8	89.8	90.0	109.0	23.5
17	»	Oct.	7. 8.30	18.5	20.7	20.8	20.8	20.8	21.0	20.8	4.77	4.80	4.65	4.70	4.60	4.70	90.6	91.5	88.5	89.5	88.0	24.7
18	»	»	19. 10.30	17.8	18.3	18.9	19.0	19.0	19.2	18.9	5.12	4.95	4.95	4.85	4.95	4.96	93.3	91.5	91.5	89.5	91.5	24.1
19	»	Nov.	6. 9.00	17.0	15.4	15.5	15.5	15.7	15.8	15.6	5.20	5.15	5.10	5.10	5.10	51.3	90.0	90.0	89.0	89.0	89.0	24.4
20	»	»	16. 9.45	11.2	14.4	14.5	14.5	14.5	14.5	14.5	5.13	5.12	5.12	5.10	51.5	5.12	87.5	87.5	87.5	87.5	87.5	24.6
21	»	Dec.	1. 9.00	8.5	11.8	13.0	13.3	13.3	13.4	13.0	5.25	5.10	5.15	5.10	51.0	5.12	85.1	84.8	86.4	85.5	85.5	24.1
1933 (mean)	—	——		13.67	13.7	13.6	13.4	13.1	12.9	13.36	5.99	6.00	6.12	6.18	6.15	6.15	—	—	—	—	—	23.3
22	1934	Jan.	6. 10.00	6.0	8.4	8.8	9.1	9.2	9.2	8.9	5.95	5.80	5.83	5.79	5.76	5.14	90.0	89.0	90.1	8.99	89.7	24.4
23	»	»	19. 9.40	6.0	7.5	7.5	7.5	7.5	7.6	7.5	5.85	6.00	6.00	5.90	5.96	5.94	86.8	89.3	87.3	87.4	89.0	24.6
24	»	Feb.	3. 9.15	3.2	5.8	6 4	6.5	6.5	6.5	6.3	6.50	6.32	6.43	6.35	6.30	6.38	93.3	91.9	93.5	92.6	92.3	24.7
25	»	»	18. 10.00	3.3	5.7	6.4	6.8	6.8	6.8	6.5	6.52	6.54	6.36	6.39	6.30	6.42	93.1	95.4	93.5	94.1	92.8	25.1
26	»	Mar.	8. 9.20	8.0	6.7	6.7	6.8	6.9	6.8	6.8	6.43	6.32	6.27	6.30	6.27	6.32	94.0	92.6	91.8	92.8	92.5	25.0
27	»	»	21. 9.20	9.5	6.8	6.9	6.9	7.0	6.9	6.9	6.88	6.98	6.98	6.83	6.93	6.92	100.0	102.5	102.5	100.5	102.2	23.8
28	»	Apr.	1. 9.20	8.0	6.0	6.2	6.2	6.2	6.4	6.2	6.72	6.41	6.67	6.52	6.62	6.59	96.7	92.6	96.5	94.8	96.5	24.7
29	»	»	20. 8.30	10.5	8.2	7.5	7.5	7.2	6.8	7.4	6.56	6.41	6.46	6.36	6.36	6.43	95.1	95.1	96.1	94.3	94.0	19.9
30	»	May	2. 9.30	11.2	8.2	8.2	8.2	8.2	8.2	8.2	6.46	6.51	6.53	6.50	6.56	6.51	96.8	98.2	98.5	98.2	99.1	23.9

Specific gravity $\left(S\frac{15}{4}\right)$					pH						Forel's scale No.	Transparency (m)	Volume of plankton per m³ in c.c.						Weather
5	10	20	30	(mean)	O_m	5	10	20	30	(mean)			O_m	5	10	20	30	(mean)	
													c.c.						
4.35	24.55	24.58	24.73	24.49	8.20	8.20	8.20	8.20	8.20	8.20	4.5	12.0	113.33	160.00	166.66	193.33	213.33	169.33	snow, calm
4.52	24.60	24.60	24.60	23.95	8.22	8.22	8.22	8.22	8.22	8.22	4.0	14.0	50.00	53.33	66.66	63.33	63.33	54.33	fine, calm
4.81	24.86	24.91	24.91	24.82	8.22	8.22	8.22	8.22	8.22	8.22	4.0	19.0	103.33	166.06	116.66	116.66	126.66	115.99	"
4.71	24.71	24.71	24.72	24.70	8.20	8.20	8.20	8.20	8.20	8.20	4.0	19.0	120.00	106.66	113.33	170.00	116.66	125.33	cloudy, calm
4.68	24.80	24 80	24.86	24.65	8.30	8.26	8.26	8.26	8.26	8.27	4.5	11.0	366.66	350.00	380.00	333.33	383.33	312.66	cloudy, breeze N.E.
4.61	24.78	24.78	25.04	22.58	8.10	8.20	8.20	8.20	8.20	8.18	6.0	6.5	206.66	550.00	433.33	600.00	1000.00	557.99	cloudy, calm
4.66	24.72	24.82	24.85	24.71	8.20	8.20	8.20	8.20	8.20	8.20	4.0	14.0	700.00	701.66	643.38	883.33	1366.66	859.00	fine, breeze E.
4.66	24.71	24.71	25.00	23.75	8.20	8.20	8.20	8.20	8.20	8.20	5.0	9.0	333.33	666.66	660.00	283.33	473.33	241.67	fine, breeze S.W.
3.91	24.08	24.48	24.48	23.56	8.25	8.23	8.20	8.20	8.20	8.22	5.0	9.5	—	486.66	416.66	276.66	266.66	361.66	fine, breeze N.
4.23	24.23	24.38	24.43	24.28	8.20	8.20	8 22	8.22	8.20	8.21	5.0	7.5	246.66	236.66	200.00	493.00	566.66	348.60	cloudy, breeze E.
4.50	25.60	25.53	25.53	25.29	8.25	8.25	8.22	8.22	8.22	8.23	4.0	12.0	46.60	33.33	166.66	40.00	86.66	74.66	cloudy, breeze E.
4.76	24.31	24.33	24.33	24.60	8.20	8.20	8.20	8 22	8.20	8.20	4.0	9.0	193.33	183.33	216.66	183.33	286.66	212.66	cloudy, breeze W.
3.52	25.64	25.84	26.00	25.02	8.20	8.22	8.25	8 28	8.28	8.25	3.5	13.0	383.33	366.66	400.00	790.00	233.33	434.66	fine, breeze E.
4.82	25.02	25.07	25.13	24.90	8.25	8.25	8.22	8.22	8.22	8.23	3.5	16.5	483.33	146.66	166.66	193.33	126.66	223 32	fine, breeze N.E.
4.64	25.05	24.90	25.23	24.91	8.28	8.25	8.25	8.22	8.20	8.24	3.5	13.0	600.00	126.66	266.66	266.66	166.66	285.33	fine, breeze N.E.
4.32	24.40	24.55	24.70	24.30	8.25	8.25	8.25	8.22	8.20	8.23	4.0	15.0	290.00	383.33	333.33	153.33	83.33	228.66	fine, breeze S.
4.98	24.78	24.83	24.93	24.82	8.26	8.26	8.26	8.26	8.26	8.26	4.0	11.0	13.33	10.00	10.00	10.00	10.00	10.66	cloudy, breeze W.
4.51	24.56	24.53	24.53	24.46	8.26	8.28	8.25	8.25	8.25	8.26	5.0	9.5	13.33	16.66	16.66	16.66	13.33	15.33	cloudy, breeze N.E.
4.62	24.64	24.70	24.70	24.61	8.25	8.25	8.25	8.25	8.25	8.25	5.0	13.0	50.00	30.00	33.33	33.33	33.33	36.00	cloudy, breeze W.
4.65	24.65	24.75	24.77	24.69	8.22	8.22	8.22	8.22	8.22	8.22	4.0	12.5	26.66	20.00	16.66	20.00	16.66	20.00	cloudy, breeze E.
4.55	24.73	24.73	24.73	24.57	8.22	8.22	8.22	8.22	8.22	8.22	5.0	10.5	33.33	26.66	30.00	33.33	33.33	31.33	fine, breeze E.
4.55	24.73	24.79	24.87	24.46	8.225	8.228	8.224	8.227	8.220	8.224	—	—	218.66	227.22	231.11	245.38	269.88	242.72	——
5.08	25.13	25.26	25.29	25.05	8.25	8.25	8.26	8.26	8.25	8.25	4.0	16.0	20.00	20.00	20.00	16.66	20.00	19.33	cloudy, breeze N.E.
4.99	24.91	24.91	24.92	24.88	8.22	8.22	8.22	8.22	8.22	8.22	4.0	18.0	36.66	36.66	36.66	40.00	40.00	33.00	cloudy, breeze S.W.
5.86	25.01	25.12	25.25	25.00	8.20	8.20	8.20	8.20	8.20	8.20	3.5	16.5	6.66	13.33	16.66	16.66	16.66	13.99	cloudy, breeze E.
5.18	25.33	25.26	25.35	25.25	8.26	8.25	8.25	8.25	8.24	8.25	3.5	20.5	13.33	13.33	16.66	16.66	16.66	15.33	snow, breeze E.
5.05	25.09	25.17	25.17	25.10	8 20	8.20	8.20	8.20	8.20	8 .20	3.0	25.0	33.33	26.66	26.66	26.66	26.66	28.00	fine, breeze E.
4.78	24.88	25.13	25.22	24.76	8.27	8.26	8.26	8.26	8.26	8 26	5.0	6.0	833.33	340.00	310.00	266.66	413.33	432.66	cloudy, breeze S.
4.87	25.02	25.12	24.88	24.92	8.20	8.20	8.20	8.20	8.20	8.20	5.0	8.5	466.66	566.66	206.66	273.33	260.00	354.66	fine, calm
5.03	24.85	24.92	25.12	23.78	8.20	8.25	8.25	8.25	8.25	8.24	4.0	13.5	26.66	113.33	120.00	66.66	360.00	137.33	fine, breeze N.
4.46	24.81	24.88	25.02	24.62	8.20	8 18	8.18	8.18	8.18	8.18	4.0	14.0	93.33	140.00	273.33	246.66	25.000	200.66	cloudy, breeze W.

No. of exp.	Date of observation				Air temp. °C.	Water temp. °C.						O_2 c.c./L						Percent. saturation of O_2					
						O_m	5	10	20	30	(mean)	0_m	5	10	20	30	(mean)	0_m	5	10	20	30	0
				(a.m.)																			
31	1934	May	18.	11.00	18.5	14.8	10.6	10.3	9.8	9.0	10.9	6.04	6.14	6.33	6.28	5.93	6.41	100.00	97.1	100.1	98.2	91.0	20.
32	"	June	1.	9.30	19.2	13.5	12.3	11.8	11.3	9.6	11.7	6.20	6.22	6.33	6.20	5.04	6.00	102.10	101.6	103.1	99.9	78.4	22.
33	"	"	16.	9.30	23.0	17.2	15.5	15.2	13.6	13.3	15.0	5.83	5.88	5.88	6.21	6.21	6.00	104.00	102.0	101.7	104.1	104.1	24.
34	"	July	17.	9.00	21.5	18.3	17.6	17.3	17.0	15.5	17.1	5.46	5.46	5.41	5.56	5.36	5.45	100.0	99.0	97.2	99.5	92.5	24.
35	"	Aug.	1.	9.00	21.5	21.5	19.5	18.3	16.8	16.3	18.5	4.92	4.66	5.14	4.60	4.39	4.74	92.6	86.6	93.8	82.0	77.9	21.
36	"	Sept.	2.	9.00	24.0	21.2	21.1	21.3	21.3	19.6	20.9	4.28	4.66	4.60	4.39	4.12	4.41	81.6	89.1	87.8	83.9	76.8	24.
37	"	"	17.	9.20	25.4	21.0	20.9	20.9	21.0	20.7	20.9	4.77	4.61	4.60	4.69	5.19	4.77	90.0	87.5	87.3	89.2	98.1	23.
38	"	Oct.	3.	9.00	17.0	19.1	19.6	19.9	20.0	20.0	19.7	4.93	4.70	4.60	4.55	4.60	4.68	90.5	80.9	86.0	85.5	86.5	23.
39	"	"	16.	9.25	15.4	17.5	18.2	18.2	18.4	18.5	18.2	5.01	5.04	5.12	4.87	3.85	4.80	89.5	91.2	94.8	88.8	70.4	23.
40	"	Nov.	1.	9.30	14.0	15.7	15.8	16.3	16.6	16.5	16.2	5.78	5.70	5.27	5.31	5.29	5.47	100.5	100.0	93.0	94.3	94.0	24.
41	"	"	18.	9.30	13.0	14.0	14.5	14.6	14.7	14.7	14.5	5.71	5.60	5.20	5.29	5.18	5.40	96.5	95.8	88.8	90.5	88.8	24.
42	"	Dec.	8.	9.00	9.0	9.5	10.2	10.5	10.5	10.5	10.2	6.11	6.26	6.26	6.45	5.75	6.16	94.5	98.0	98.6	101.5	91.0	23.
43	"	"	17.	9.00	11.0	9.0	9.5	9.9	10.0	10.2	9.7	6.07	6.58	6.54	6.63	6.63	5.66	92.4	101.8	102.2	103.7	104.0	23.
1934 (mean)	—		—		13.55	12.5	12.3	12.3	12.1	11.8	12.2	5.77	5.86	5.86	5.82	5.66	6.49	—	—	—	—	—	23.
44	1935	Jan.	4.	9.40	10.2	9.6	9.4	9.0	8.9	8.6	9.1	6.24	6.25	6.24	6.42	6.32	6.29	96.8	96.8	96.2	98.5	96.4	24.
45	"	Feb.	3.	9.00	1.8	8.3	8.4	8.4	8.5	8.5	8.4	6.28	6.25	6.42	6.31	6.20	6.29	94.5	95.4	98.8	96.6	94.5	24.
46	"	Mar.	4.	9.00	7.8	7.5	7.6	7.6	7.6	7.5	7.6	6.80	6.90	6.89	6.90	6.92	6.88	100.7	102.3	102.3	102.3	102.3	24.
47	"	"	19.	9.00	9.5	6.4	6.5	6.5	6.5	6.5	6.5	7.28	7.33	7.40	7.38	6.85	7.25	105.0	106.2	107.2	107.1	99.6	24.
48	"	Apr.	8.	9.00	9.5	7.0	6.8	7.0	7.0	7.0	7.0	—	—	—	—	—	—	—	—	—	—	—	
49	"	"	16.	9.00	8.0	7.6	7.2	7.2	7.2	7.0	7.2	7.03	6.89	6.96	6.82	6.89	6.92	104.3	101.5	102.5	100.5	101.2	24.
50	"	May	4.	8.30	13.0	8.5	8.4	8.3	8.3	8.3	8.4	6.43	6.40	6.37	6.29	6.24	6.35	96.3	97.5	95.5	95.3	94.8	23.
51	"	June	6.	9.00	21.0	15.0	14.2	14.0	12.0	10.5	13.1	6.05	6.11	6.34	6.37	5.86	6.15	104.3	103.8	107.3	103.6	96.3	24.
52	"	"	16.	9.00	22.0	16.0	14.8	14.0	13.5	13.0	13.4	5.68	5.72	5.72	5.73	5.76	5.72	97.7	99.0	97.3	96.4	96.5	24.
53	"	July	19.	8.40	20.0	19.1	18.8	18.5	17.6	17.5	18.4	5.19	5.21	5.35	5.28	5.15	5.24	96.3	96.5	98.4	96.0	93.5	25.
54	"	Aug.	4.	8.50	26.5	22.5	21.5	21.5	20.0	19.5	21.0	5.54	5.46	5.46	5.39	4.93	5.36	108.0	108.0	105.0	101.0	92.0	24.
55	"	"	18.	9.00	27.5	21.6	20.7	20.2	19.3	18.3	20.0	5.56	5.55	5.59	5.37	4.82	5.39	109.0	106.5	105.5	100.0	88.0	24.
56	"	Sept.	16.	9.00	19.5	19.0	20.0	20.5	20.9	20.8	20.2	5.26	5.04	4.96	4.70	3.76	4.74	95.6	93.5	92.6	98.8	71.5	22.
57	"	Oct.	2.	9.00	20.5	19.7	19.7	20.0	20.0	19.8	19.8	5.04	5.00	4.96	4.50	4.08	4.72	93.6	93.0	93.0	84.5	71.1	24.
58	"	"	18.	9.00	20.7	18.9	18.8	18.9	19.0	19.4	19.0	5.14	5.18	5.17	4.66	4.45	4.92	94.7	95.5	95.6	91.2	83.0	24.
59	"	Nov.	3.	9.00	14.5	13.0	16.7	17.0	17.0	17.1	16.2	5.76	5.14	5.09	5.18	4.90	5.21	92.8	91.0	91.0	92.5	87.8	20.
60	"	Dec.	1.	9.00	7.2	10.6	11.8	12.0	12.1	12.3	11.8	6.20	5.80	5.90	5.78	5.62	5.82	97.6	94.2	96.0	94.4	91.8	23.
1935 (mean)	—		—		15.25	13.3	13.61	13.56	13.26	11.8	13.12	5.97	5.89	5.95	5.93	5.82	5.91	—	—	—	—	—	23.

e II.

Specific gravity $\left(S\frac{15}{4}\right)$						pH						Forel's scale No.	Transparency (m)	Volume of plankton per m^3 in c.c.						Weather
n	5	10	20	30	(mean)	0_m	5	10	20	30	(mean)			0_m	5	10	20	30	(mean)	
08	24.40	24.48	24.48	24.50	23.59	8.20	8.22	8.25	8.25	8.25	8.23	5.0	10.0	1050.00	902.66	1080.00	836.66	770.00	928.58	sunny, calm
30	24.22	24.27	24.30	24.91	24.00	8.20	8.22	8.22	8.22	8.22	8.22	5.0	6.5	716.66	200.00	203.33	303.33	83.33	301.33	fine, breeze N.
06	24.21	24.21	24.44	24.41	24.27	8.22	8.25	8.25	8.25	8.25	8.24	4.0	10.0	70.00	100.00	53.33	93.33	36.66	70.66	fine, calm
71	24.73	24.71	24.82	24.87	24.77	8.20	8.20	8.20	8.22	8.22	8.21	4.0	15.0	33.33	40.00	40.00	40.00	40.00	38.99	fine, breeze W.
22	24.31	24.76	24.76	24.95	24.00	8.20	8.24	8.28	8.28	8.28	8.26	5.0	8.0	23.33	10.00	10.00	26.66	33.33	56.66	fine, breeze E.
60	24.62	24.62	24.62	24.64	24.62	8.28	8.28	8.28	8.28	8.20	8.26	4.0	11.0	500.00	516.66	416.66	203.33	166.66	360.66	»
30	24.31	24.37	24.45	24.65	24.28	8.28	8.28	8.28	8.27	8.26	8.27	5.0	9.5	366.66	333.33	316.66	216.66	200.00	306.66	fine, calm
38	23.84	14.07	24.19	24.10	23.98	8.30	8.30	8.28	8.25	8.25	8.28	6.0	7.5	453.33	416.66	456.66	406.66	513.33	449.33	fine, breeze W.
56	24.12	24.32	24.32	24.65	24.17	8.28	8.28	8.26	8.25	8.20	8.25	5.0	8.0	416.66	333.33	366.66	350.00	93.33	292.00	cloudy, breeze W.
20	24.54	24.42	24.91	24.91	24.60	8.30	8.30	8.30	8.20	8.20	8.26	4.0	9.5	210.00	210.00	160.00	133.33	133.33	169.33	fine, breeze N.E.
07	24.15	24.32	24.40	24.50	24.29	8.25	8.25	8.26	8.26	8.26	8.26	5.0	10.0	15.00	15.00	15.00	15.00	25.00	17.00	fine, calm
83	24.02	24.08	24.13	24.28	24.08	8.20	8.20	8.20	8.20	8.20	8.20	5.0	12.5	55.00	60.00	30.00	30.00	50.00	45.00	»
99	24.30	24.36	24.35	24.38	24.82	8.25	8.25	8.25	8.25	8.25	8.25	4.0	15.5	86.66	80.00	33.33	40.00	60.00	60.00	sunny, breeze N.
65	24.50	24.64	24.73	24.82	24.28	8.24	8.21	8.24	8.24	8.23	8.24	—	—	246.66	223.98	191.30	171.13	164.01	196.87	—
55	24.67	24.63	24.62	24.62	24.62	8.28	8.28	8.26	8.26	8.22	8.26	4.0	18.0	35.00	30.00	75.00	100.00	160.00	86.00	fine, breeze S.W.
69	24.75	24.71	24.86	24.91	24.78	8.25	8.25	8.25	8.25	8.25	8.25	3.5	17.0	83.33	76.66	80.00	83.33	86.66	82.00	snow, calm
71	24.71	24.76	24.74	24.81	24.75	8.23	8.25	8.25	8.26	8.30	8.25	4.5	14.5	115.00	135.00	200.00	375.00	400.00	245.00	cloudy, breeze S.W.
13	24.82	24.83	24.88	24.97	24.73	8.25	8.25	8.25	8.25	8.25	8.25	5.0	12.0	502.00	640.00	640.00	500.00	700.00	596.50	fine, calm
—	—	—	—	—	—	8.20	8.20	8.20	8.20	8.20	8.20	4.0	14.5	175.00	240.00	280.00	260.00	325.00	256.00	fine, wind W.
41	24.43	24.51	24.50	24.55	24.48	8.20	8.22	8.22	8.22	8.22	8.22	4.0	13.5	275.00	300.00	325.00	400.00	575.00	375.00	fine, breeze W.
05	24.83	24.88	24.88	24.88	24.50	8.20	8.22	8.22	8.23	8.23	8.22	6.0	6.3	120.00	350.00	490.00	490.00	450.00	380.00	sunny, breeze S.W.
40	24.61	24.56	25.01	25.01	24.72	8.22	8.22	8.22	8.20	8.15	8.20	5.0	7.0	250.00	250.00	160.00	200.00	410.00	254.00	sunny, calm
27	24.75	24.80	25.00	25.00	24.76	8.23	8.23	8.23	8.23	8.20	8.22	4.0	10.5	60.00	60.00	60.00	60.00	60.00	60.00	fine, calm
00	25.20	25.27	25.22	25.32	25.20	8.28	8.28	8.28	8.28	8.28	8.28	3.0	18.0	100.00	100.00	75.00	150.00	200.00	125.00	fine, breeze N.
43	24.68	24.68	24.78	24.78	24.67	8.28	8.28	8.28	8.28	8.20	8.26	4.0	11.5	1125.00	800.00	700.00	552.50	600.00	755.60	fine, breeze E.
64	24.82	24.84	24.94	25.09	24.87	8.30	8.30	8.28	8.28	8.22	8.28	5.0	9.5	325.50	275.50	300.00	300.00	225.00	285.50	fine, calm
32	23.32	24.72	24.50	24.85	23.94	8.30	8.30	8.30	8.27	8.25	8.28	5.5	7.5	750.00	425.00	325.00	150.00	80.00	346.00	fine, breeze E.
00	24.11	24.36	24.71	24.82	24.40	8.30	8.30	8.28	8.25	8.22	8.27	4.5	11.0	175.00	175.00	130.00	150.00	60.00	138.00	fine, breeze N.W.
44	24.47	24.57	24.92	24.88	24.66	8.28	8.28	8.28	8.28	8.22	8.27	4.5	13.5	75.00	75.00	80.00	65.00	75.00	74.00	fine, calm
62	24.15	24.30	24.40	24.60	23.61	8.30	8.30	8.30	8.30	8.30	8.30	5.5	5.5	215.00	230.00	180.00	200.00	200.00	205.00	»
59	24.19	24.30	24.26	24.22	24.83	8.30	8.30	8.30	8.30	8.30	8.30	4.5	10.5	40.00	32.00	33.30	32.00	35.00	34.46	fine, breeze S.E.
95	24.53	24.57	24.76	24.83	24.11	8.26	8.26	8.26	8.26	8.24	8.25	—	—	260.08	244.36	242.96	239.28	273.04	253.99	—

Studies on the Vertical Distribution of the Plankton Crustacea

II. The Reversal of Phototropic and Geotropic Signs of the Plankton Crustacea with Reference to the Vertical Movement

By

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(With 19 Tables)

I. Introduction

Studies on the vertical distribution of plankton animals have been undertaken by previous investigators, either observational or experimental, exclusive of Esterly (1911, 1912, 1917, 1919). To ascertain in what way the plankton crustaceans respond to changes in the light intensity and water temperature some experiments were carried on during the summer of 1936 and 1937 in the Kizaki Station of the Imperial Fisheries Experimental Institute. Based upon the obtained results and the previous observations made in Lake Kizaki (Kikuchi, 1927, 1930, 1937), some factors concerning the vertical movement of plankton crustaceans are discussed here in some details.

Before proceeding further, it might be mentioned that this investigation was prosecuted by a grant from the Hattori Gratitude Foundation. Taking this opportunity I wish to thank Prof. T. Kaburaki of the Tokyo Imperial University for criticism and Messrs. M. Kawajiri and K. Hata of the Kizaki Station for facilities given in the laboratory.

II. Material and Method

The materials used for experiments are the adults of the following species: *Acanthodiaptomus pacificus* var. *yamanacensis*, *Daphnia longispina*, *Polyphemus pediculus*, *Bosminopsis deitersi*, *Holopedium gibberum*, *Diaphanosoma brachyurum*, and *Leptodora kindtii*. They

were collected vertically from the bottom to the surface in Lake Kizaki by means of a plankton net and kept in large dishes in the dark room. As needed they were picked out of the stock by a large pipette. Some species could be kept alive for several days in the laboratory, but their collection was made in the morning of the day, on which day they were subjected to experiments.

There occurs an abrupt change in environmental conditions when the animals are brought to the laboratory. Though it is hard to say what effect this exerts on the responses of animals in the laboratory, the results of the experiments are, so far as signs of tropism are concerned, uniform in cases tested with animals which are kept in darkness for a considerable length of time.

For ascertaining the phototropism of animals, ten to forty specimens were enclosed in a glass tube 5 cm. in diameter and 30 cm. in length, which was filled with water and its length was marked off into five equal divisions. One end of the tube was sealed with a glass plate and the other end with a cork stopper painted with black enamel, through which a curved rod thermometer was secured. The tube was suspended horizontally in a water bath and was illuminated through one end. In examining the direction of the movement and the distribution of animals in the tube, the phototropic signs were determined. Before the experiment the animals were adapted in darkness for some fifteen minutes.

The light source used was a carbon arc lamp of 100 volts and 3 amperes. The lamp was enclosed in a housing of black sheet iron. The light intensity was decreased or increased by changing the distance between the tube and the lamp and was measured by the thermopiles of the Oyama solarimeter and the Mazda Selenium rectifier photoelectric cell. The experiments were carried on at distances of 5, 10, 20, 30, 50, 75, 100, and 150 cm., where the light intensities were 91.5, 54.9, 23.8, 13.7, 5.49, 2.75, 1.83, and 1.37 mW/cm^2/min respectively and at temperatures of about 13, 15, 20, 25, and 28°C. In some experiments the Lifa light-filters Nos. 294(red), 375(yellow), 210(green), and 208(blue) were employed. A series of experiments was made for three or four hours to make observations every ten or twenty minutes. It might be noticed that the light intensity was reduced by 94 percent at the far end of the tube when measured by the Selenium cell, but by 2 percent when measured by the solarimeter.

For studying the geotropism of animals the glass tube in which

they were enclosed was kept vertically in a cylindrical glass jar filled with water. The jar was placed in a box painted with white enamel, one side of which was provided with a white opaque glass plate for keeping the tube in diffuse light. The water temperature in the tube was regulated by heating or cooling the water in the jar. The light source used was a carbon arc lamp and Mazda lamps. In examining the distribution of animals in the tube, the geotropic signs were determined.

III. Experimental Results

1. Acanthodiaptomus pacificus var. yamanacensis

A. Phototropism

So far as the experiments go, no evidence for believing in the reversal of the phototropic signs with changes in the light intensity and water temperature are demonstrated. In all experiments the animals are found to be crowded at the positive end of the tube, exclusive of a few individuals which swim about in the middle sections of the tube. The results are so consistent that further comment is unnecessary.

B. Geotropism in darkness

Table I serves as one example showing the geotropism of the animals in darkness at low temperatures. When the animals which

Table I. The changing distribution of specimens of *Acanthodiaptomus pacificus* var. *yamanacensis* in darkness.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
9.36 A.M.	13.0	1	0	0	1	37
9.56	13.0	5	3	2	6	21
10.10	13.2	8	4	5	7	15
10.20	13.4	7	5	4	8	15
10.45	13.6	8	3	5	7	16
11.30	13.8	8	3	2	8	18
12.05 P.M.	14.0	7	4	3	7	18
12.50	13.4	3	2	4	10	20
2.05	14.2	3	4	5	11	16
4.15	14.3	2	3	5	8	21

are positively geotropic in diffuse light are brought in complete darkness at temperatures of 13.0–14.3°C, about half of them show a slight tendency toward the negative geotropism and ascend to the top of the tube, the maximum number at the top being found from 40 minutes to 2 hours after the experiment is commenced. The remaining half are, however, indifferent to gravity or positively geotropic and retain their position near the bottom. Two hours following the experiment there is noticed a slight tendency to the decrease in number of individuals at the top of the tube.

In comparing the behavior of the animals in darkness at high temperatures with that at low temperatures, it is proved that the temporary negative geotropism in darkness is more evidently demonstrated at high temperatures, and that the animals are more uniformly distributed. The figures given in Table II offers evidences of these tendencies.

Table II. The changing distribution of specimens of *Acanthodiaptomus pacificus* var. *yamanacensis* in darkness.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
10.08 A.M.	25.2	0	0	0	2	23
10.20	25.2	5	3	4	3	10
10.40	25.3	6	4	3	3	9
11.10	25.3	5	4	2	6	8
11.40	25.2	5	4	3	5	8
12.10 P.M.	25.2	4	3	3	5	10
12.55	25.1	2	4	4	6	9
1.30	25.1	3	3	5	5	9
2.20	25.0	3	2	4	7	9
3.10	24.9	2	4	3	6	10
4.20	24.8	3	4	4	5	9

Table III serves as one example showing that the change in the water temperature exerts no influence upon the geotropic response of the animals in darkness.

C. Geotropism in diffuse light

As is seen in Table IV, the animals become positively geotropic when they are suddenly brought from darkness to diffuse light of any

Table III. The changing distribution of specimens of *Acanthodiaptomus pacificus* var. *yamanacensis* in darkness as the water temperature is lowered and then raised. The animals were kept in darkness at 22.5°C from the preceding evening.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
10.55 A.M.	22.5	3	5	2	6	12
11.00		cooled				
11.25	15.9	4	3	3	7	11
12.05 P.M.	15.8	3	3	2	8	12
2.00	15.7	4	2	1	5	16
2.02		heated				
2.10	19.2	3	3	1	7	14
2.30	25.5	3	3	2	9	11
2.40	27.5	2	3	4	8	11
3.30	27.7	4	4	3	8	9

intensity. After being kept in a constant condition for one or two hours, however, they become indifferent to gravity. The same holds good when the animals are brought in darkness from light. This state of things appears to be not true, so far as the experiments go, in the case of changes in the light intensity from weak to strong or vice versa. This similarity is also true of other experiments which are performed at low temperatures.

Table IV. The changing distribution of specimens of *Acanthodiaptomus pacificus* var. *yamanacensis* in diffuse light and darkness.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
10.30 A.M.	28.5	brought in darkness				
10.40	28.5	2	3	3	18	19
11.25	28.4	3	5	5	12	20
11.52	28.3	4	5	3	11	22
11.58	28.2	brought in diffuse light				
12.05 P.M.	28.0	0	1	2	5	37
12.35	28.0	0	2	1	6	36
1.20	27.9	1	2	1	8	33
1.40	27.9	2	2	5	8	27
2.00	27.9	3	2	5	8	27
3.00	27.8	5	6	8	12	14
4.20	27.8	4	4	9	11	17
4.35	27.8	brought in darkness				
4.40	27.8	1	0	0	10	34
5.20	27.8	3	2	2	9	29

Table V. The changing distribution of specimens of *Acanthodiaptomus pacificus* var. *yamanacensis* in diffuse light as the water temperature is changed. The animals were kept in diffuse light at 22.4°C from 10.30 A.M.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
12.30 P.M.	22.4	5	6	6	8	14
12.45		cooled				
1.00	16.8	0	0	1	0	38
1.15	14.2	0	0	0	0	39
1.30	14.2	0	0	0	0	39
1.50	14.1	0	0	1	1	37
2.20	14.1	1	1	3	2	32
3.30	14.2	3	2	2	8	22
3.50	14.3	2	4	2	8	23
3.51		heated				
4.00	18.5	0	0	2	9	28
4.10	22.2	0	1	0	5	33
4.30	22.5	1	0	1	7	30
5.00	22.8	5	2	3	7	22

Table V offers evidences that a marked tendency to the temporary positive geotropism of the animals is produced by changing the water temperature in diffuse light.

D. Movement in vetrical light from above

The animals move upward to any intensity of light at any temperature, to result in their crowds being quite near the surface if the uniform condition is maintained. The upward movement is, however, retarded when the animals are exposed to light from the above soon after the water temperature is raised. The speed of the upward movement is as fast as 50–80 cm/min at 22°C, the mean being 62 cm/min.

2. *Daphnia longispina*

A. Phototropism

Inspection of Table VI shows that the animals are positively phototropic when they are exposed to light after being kept in darkness for some time, and that the majority of the animals become indifferent to light when the uniform condition is maintained for half an hour or more.

Following a sudden increase in the light intensity the animals dash widely about for a few minutes, and then the majority become temporarily negatively phototropic. This temporary sign persists for only a few minutes and regains normality. A reduction in the light intensity strengthens the positive response.

Further a slight tendency to the negative phototropism is produced by sudden raising or lowering of the water temperature, though the response regains its original sign soon after the water temperature becomes constant.

Table VI. The phototropism of *Daphnia longispina*. The animals were brought from darkness and illuminated by horizontal light from a 250-Watt lamp at a distance of 20 cm.

Time	Temp. (°C)	Number of specimens in the sections				
		I(pos.)	II	III	IV	V(neg.)
1.40 P.M.	19.8	26	0	0	0	0
2.00	19.9	23	0	0	1	2
2.08	20.1	18	3	2	1	2
2.21	20.2	15	2	1	0	7
2.32	20.2	10	2	3	4	7
2.45	20.3	12	3	2	2	7
3.05	20.4	10	2	3	3	8
3.30	20.4	11	3	2	3	7

As regards the phototropism of daphnids, Rose (1925) points out that *Daphnia longispina* is of the positive phototropism, but some investigators state that *Daphnia pulex* is primarily negatively phototropic (Clarke, 1930), permanently positively phototropic (Yerks, 1900), and positive to weak light but negative to strong light (Dice, 1914). Furthermore, the reversal of the phototropic sign induced by changes in the light intensity has hitherto been recorded by Ewald (1910), Dice (1914), Mast (1921), Rose (1925), and Clarke (1930).

B. Geotropism in darkness

Table VII is of an usual form that deals with the geotropic responses of the animals in darkness at low temperatures. It is shown that the great majority of the animals are positively geotropic but a minority indifferent to gravity. Other experiments which are carried on at high temperatures indicate that increase of the temperature

Table VII. The changing distribution of specimens of *Daphnia longispina* in darkness. The animals were brought in darkness after being kept in diffuse light for half an hour at 13.0°C.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
9.40 A.M.	13.0	2	2	3	5	24
9.55	13.0	3	2	2	7	22
10.12	13.5	4	3	2	6	21
10.44	13.7	3	3	2	6	22
11.05	13.8	6	3	3	5	21
11.30	14.2	5	3	4	4	20
12.00 P.M.	14.2	6	2	3	6	19
12.50	14.2	4	3	4	5	20
1.20	14.4	5	2	3	6	20
2.05	14.4	6	4	2	9	15
4.15	14.5	4	3	2	6	21

causes a tendency to decrease of the positive phototropism, resulting in the uniform distribution of the animals.

The influence of a sudden change in the water temperature upon the geotropism in darkness is well shown in Table VIII. When raising the temperature from 14°C to 25°C, the animals show a marked tendency

Table VIII. The changing distribution of specimens of *Daphnia longispina* in darkness as the water temperature is raised. The number of animals suspended at the water surface with air bubbles is given in brackets.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
12.00 P.M.	13.8	5	0	0	0	29
12.15	13.8	7	0	1	3	23
12.35	14.2	12	2	0	9	11
12.55	13.8	7	3	2	4	18
1.20	14.0	8	3	5	3	15
1.25		heated				
1.40	19.2	(3)	0	0	0	31
1.50	24.4	(3)	0	0	0	31
2.15	25.2	(3)	0	0	0	31
2.40	25.3	(3)1	1	0	3	26
3.10	25.3	(3)3	2	2	4	20

to the positive geotropism. This tendency persists for two or three hours after which they regain normal response. In these experiments some specimens are found to be suspended at the surface of the water with air bubbles. By lowering the water temperature from 23°C to 13°C, the same tendency to the positive geotropism is observed. This state of things is not in coincidence with that obtained by DICE (1914) in *Daphnia pulex*. He shows that high temperatures produce a tendency to the positive geotropism but low temperatures to the negative.

C. Geotropism in diffuse light

The behavior of daphnids in diffuse light shows a similar tendency to that of *Acanthodiaptomus pacificus* var. *yamanacensis* mentioned above. The animals are indifferent to gravity in any intensity of light and at any temperature when they are kept in the uniform condition for a considerable length of time (Table IX). If they are suddenly exposed to light from darkness, however, there is a slight tendency to the positive geotropism which lasts for half an hour. Furthermore, a

Table IX. The changing distribution of specimens of *Daphnia longispina* in diffuse light as the water temperature is lowered. The animals were kept in darkness at a temperature of 21°C from the preceding evening.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
10.35 A.M.	21.8	6	5	6	7	14
10.40	21.8	brought in diffuse light				
10.45	21.8	2	1	3	8	22
11.00	21.8	3	3	6	9	15
11.30	21.8	8	7	5	8	8
12.00 P.M.	21.8	8	8	6	6	8
12.30		cooled				
12.45	18.2	0	0	1	0	35
1.00	16.5	0	0	0	0	36
1.15	14.2	0	0	0	0	36
1.30	14.2	0	0	0	0	36
2.30	14.5	0	0	0	0	36
2.45	14.2	0	0	0	2	34
3.00	14.3	1	1	1	3	30
3.20	14.5	2	2	3	6	23
3.40	14.0	3	2	8	7	16
4.00	14.2	2	5	5	8	16

marked tendency to the positive geotropism is produced by lowering the water temperature. The same holds good in *Daphnia pulex,* according to Dice (1914) and Clarke (1930). Other experiments indicate that the temporary positive geotropism induced by bringing the animals to darkness from light is hardly demonstrated.

D. Movement in vertical light from above

When the animals are illuminated from above, being subjected to a sudden heating or cooling of the water, they swim downward to the bottom. Conversely they move upward to any intensity of light at any temperature when they are exposed to light after being kept in darkness for a considerable length of time. This tendency toward the upward movement diminishes when they are exposed to light for two hours or more. From these facts, it may be stated that on heating or cooling the geotropic force is stronger than the phototropic, and the reverse is true when the animals are brought to light from darkness. The speed of the upward movement is as fast as 60–100 cm/min at 21.6°C, the mean of which is 86 cm/min.

3. *Holopedium gibberum*

A. Phototropism

The great majority of the animals show a marked tendency to the positive phototropism in any intensity of light. On the contrary the minority (1–10%) are negatively phototropic or indifferent to light. The neutral animals swim back and forth in the tube. In strong light the percentage of the negatively phototropic animals increases. The same is true of the positively phototropic animals in weak light. Following a sudden increase of the light intensity the animals show a tendency to the temporary negative phototropism which lasts for several minutes. In any experiment no evidence can be noticed for believing in the existence of the reversal of the phototropic signs with changes in the water temperature.

B. Geotropism in darkness

Table X serves as one example showing that the animals which are positively geotropic in diffuse light become indifferent to gravity when they are brought to darkness. This tendency is observed one hour after they are brought in darkness, resulting in a uniform

Table X. The changing distribution of specimens of *Holopedium gibberum* in darkness. The animals were brought in darkness at 12.55 P.M. after being kept in diffuse light for one hour at 23.1°C.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
12.50 P.M.	23.1	0	0	0	2	22
1.05	23.1	0	0	0	1	23
1.30	23.1	0	0	0	0	24
1.50	23.1	0	1	0	1	22
2.15	23.2	0	2	2	3	17
2.25	23.2	1	3	2	5	13
2.46	23.2	3	2	2	4	13
3.05	23.3	2	3	3	5	11
3.20	23.3	4	3	3	6	8
3.50	23.3	3	4	3	5	9
4.20	23.3	4	4	5	4	7
9.50 A.M. next day	22.7	5	3	4	6	6

distribution in the tube within three hours. This similarity is also true of other experiments at temperatures of 14°C and 27°C.

Table XI indicates that a sudden decrease of the water temperature from 23.6°C to 16.2°C renders the animals indifferent to gravity or negatively geotropic, while a sudden increase from 16.2°C to 25.8°C produces the positive geotropism.

Table XI. The changing distribution of specimens of *Holopedium gibberum* in darkness as the water temperature is lowered and raised. The animals were brought in darkness at 14.15 A.M. from diffuse light.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
10.15 A.M.	23.6	0	0	0	3	25
10.45	23.6	3	2	0	3	20
11.00	23.6	3	3	2	5	15
11.05		cooled				
11.20	16.8	7	3	2	4	12
11.30	16.2	7	3	3	4	11
11.32		heated				
11.40	18.5	4	5	4	5	10
11.45	22.8	0	1	0	12	15
12.05 P.M.	25.6	0	1	2	8	17
1.10	25.7	2	4	4	6	12
1.50	25.8	3	5	2	8	10
3.10	25.7	3	4	4	5	12

C. Geotropism in diffuse light

Table XII serves as one example that the animals show a marked tendency toward the positive geotropism in diffuse light at any temperature; consequently they sink down to the bottom of the tube and remain there as long as the condition is maintained constantly. The increase in the light intensity seems to strengthen a tendency to the positive geotropism.

Table XII. The changing distribution of specimens of *Holopedium gibberum* in diffuse light. The animals were brought in diffuse light at 12.55 P.M. after being kept in darkness for two hours at 23.1°C.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
12.55 P.M.	23.1	2	1	1	3	18
1.00	23.1	1	0	0	8	16
1.25	23.1	0	0	0	0	25
1.45	23.1	0	0	0	0	25
2.00	23.2	0	0	0	3	22
2.25	23.2	0	0	0	5	20
3.00	23.3	0	0	0	3	22
3.50	23.3	0	0	0	2	23
9.45 A.M. (next day)	22.8	0	0	0	3	22

D. Movement in light from above

When the animals are illuminated from above, the majority swim upward to any intensity of light at any temperature. There is temporarily a slight tendency toward the downward movement when they are exposed to light after being kept in darkness or the light intensity is suddenly increased. The speed of the upward movement at 22.3°C is as fast as 18–32 cm/min, the mean of which is 23 cm/min.

4. *Polyphemus pediculus*

A. Phototropism

When the animals are exposed to horizontal light from an arc lamp at a distance of 20 cm (light intensity 23.8 mW), they are all negatively phototropic. A tendency to the positive phototropism is produced as the light intensity decreases, and at a distance of 75 cm about half of the animals become positively phototropic as is seen from Table XIII.

Table XIII. The phototropism of *Polyphemus pediculus* to various intensities of light. The asterisk indicates the experiment in which the Lifa light-filter No. 210(green) was employed. The number of the specimens in the sections was counted after being kept in the uniform condition for half an hour.

L. i. (mW)	D. (cm)	Temp. (°C)	Number of specimens in the sections				
			I(pos.)	II	III	IV	V(neg.)
54.9	10	22.1	0	0	1	1	34
23.8	20	22.1	0	1	0	2	33
13.7	30	22.1	3	1	1	0	31
5.49	50	22.1	5	0	1	7	13
2.75	75	22.1	7	2	0	6	11
1.83	100	22.1	11	3	1	3	7
*3.22	50	22.1	25	2	2	4	3

Furthermore, when the light-filter is employed, the great majority of the animals show the positive phototropism. So far as the experiments go, no evidence showing the change of the phototropic signs with changes in the water temperature is demonstrated.

B. Geotropism in darkness

The predominating positive geotropism in darkness is shown by the figures in Table XIV. So far as the experiments go, all the animals descend to the bottom after being kept in darkness for three hours. A similar tendency is observed at temperatures of about 14°C and 26°C.

Table XIV. The changing distribution of specimens of *Polyphemus pediculus* in darkness. The animals were brought in darkness after being kept in diffuse light for one hour at 23.1°C.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
12.50 P.M.	23.1	2	2	1	5	20
1.02	23.1	2	3	0	3	22
1.30	23.1	3	1	0	2	24
1.46	23.1	2	2	2	3	21
2.23	23.2	1	2	3	3	21
2.46	23.2	2	1	0	2	25
3.02	23.3	0	1	2	1	26
3.52	23.3	1	0	2	0	27
9.50 A.M. (next day)	22.8	0	1	0	2	18

C. Geotropism in diffuse light

Table XV shows that the animals are indifferent or positive to gravity in diffuse light at a temperature of about 23°C. The neutral animals swim up and down in the tube throughout the course of experiments. Experiments made at about 13°C give similar results.

Table XV. The changing distribution of specimens of *Polyphemus pediculus* in diffuse light. The animals were brought in diffuse light after being kept in darkness for one hour at 23.1°C.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
12.55 P.M.	23.1	2	3	2	5	12
1.05	23.1	3	2	5	6	8
1.25	23.1	2	3	0	5	14
1.45	23.1	2	1	3	3	15
2.25	23.2	2	2	3	2	15
3.00	23.2	5	3	2	6	8
3.20	23.3	2	3	5	3	12
3.50	23.3	6	3	5	3	7
4.10	23.3	4	4	3	5	8
9.45 A.M. (next day)	22.8	3	2	3	2	8

D. Movement in light from above

The great majority of the animals move upward to light weaker than 1.8 mW (100 cm from an arc lamp), while the minority are indifferent to light or move downward. To light intensity stronger than 23.8 mW (20 cm from the light source) the majority of the animals swim downward. The speed of the upward movement is as fast as 18–27 cm/min at 23.2°C, the mean being 23 cm/min.

5. *Bosminopsis deitersi*

A. Phototropism

The animals are indifferent to light at any temperature when they are exposed to light weaker than 54.9 mW (10 cm from an arc lamp) for a few minutes to half an hour. The neutral animals swim back and forth in the tube and no consistent direction is detected. A sudden decrease of the light intensity produces a tendency to the temporary positive phototropism, while a sudden increase to the temporary nega-

tive phototropism. To very strong light (91.5 mW or 5 cm from an arc lamp) the majority of the animals show negative phototropism, while to very weak light they show positive phototropism. Table XVI offers one example showing the phototropism of the animals to various intensities of light.

Table XVI. The phototropism of *Bosminopsis deitersi* to various intensities of light. The asterisk indicates the experiment in which the Lifa light-filter No. 210(green) was employed. The number of specimens in the sections was counted after being kept in a constant condition for half an hour.

L. i. (mW)	D. (cm)	Temp. (°C)	Number of specimens in the sections				
			I(pos.)	II	III	IV	V(neg.)
54.9	10	21.8	4	2	2	5	8
23.8	20	21.8	5	4	3	3	6
13.7	30	21.8	6	4	2	2	7
5.49	50	21.8	8	4	2	1	6
2.57	75	21.8	7	5	3	2	4
1.83	100	21.8	10	3	3	3	2
*3.22	50	21.8	16	3	1	1	0

B. Geotropism in darkness and diffuse light

Both in darkness and diffuse light the animals move up and down and no consistent tendency toward the positive or negative geotropism is found at any temperature, and even sudden changes in the light intensity and water temperature exert to tropic influence.

C. Movement in light from above

The animals swim up and down in the tube when they are exposed to light of constant intensity from above, and as a result they are more or less uniformly distributed. A sudden decrease of the light intensity produces a tendency toward the upward migration, while a sudden increase a tendency toward the downward migration. These tendencies last for a few minutes. The speed of the upward movement is as fast as 12–30 cm/min at 22.5°C, the mean being 22 cm/min.

6. *Leptodora kindtii*

A. Phototropism

The occurrence of this species is erratic in Lake Kizaki and the animals obtained are few in number. So far as a few experiments

are concerned, they are generally positively phototropic, while a sudden increase of the light intensity produces a tendency to the temporary negative phototropism, and a sudden decrease strengthens a tendency toward the positive phototropism.

B. Geotropism in darkness

The animals are seemingly indifferent to gravity as long as the temperature is maintained constant. It is difficult to say from the figures in Table XVII whether they are indifferent to gravity or negatively geotropic when they are suddenly cooled, but on heating they show temporarily a marked tendency toward the positive geotropism which lasts for about an hour.

Table XVII. The changing distribution of specimens of *Leptodora kindtii* in darkness as the water temperature is changed. The animals were brought in darkness at 10.15 A.M. after being kept in diffuse light for an hour at 23.5°C.

Time	Temp. (°C)	Number of specimens in the sections				
		I(top)	II	III	IV	V(bottom)
10.25 A.M.	23.6	0	0	0	1	2
10.45	23.6	0	1	0	1	1
11.05	23.6	1	0	0	1	1
11.10		cooled				
11.20	17.8	1	0	1	1	0
11.30	16.2	1	1	1	0	0
11.35		heated				
11.40	18.5	2	1	0	0	0
11.45	22.8	0	0	0	0	3
12.05 P.M.	25.6	0	0	0	1	2
12.45	25.7	1	1	1	0	0
1.50	25.8	3	0	0	0	0
2.20	25.8	2	1	0	0	0
3.40	25.7	2	1	0	0	0
9.30 (next day)	25.2	1	1	0	1	0

C. Geotropism in diffuse light

A marked tendency to the positive geotropism is found in diffuse light at any temperature.

b) Movement to light from above

When the animals are illuminated from above they move upward as far as 44–51 cm min at a temperature of 22.6°C, the mean being 51 cm min.

7. *Diaphanosoma brachyurum*

This species was obtained abundantly, but the great majority of the animals were suspended at the surface of the water during the course of experiments; consequently it was impossible to observe the behavior of the animals for a long period of time. So far as the experiments go, however, it appears that the animals show a tendency similar to *Holopedium gibberum*.

IV. Conditions of Life in the Lake

In Lake Kizaki the vertical distribution of plankton crustaceans as well as the water temperature and underwater illumination are as shown in Table XVIII and XIX. The collection of the plankton and

Table XVIII. The vertical distribution of planktonic crustaceans in Lake Kizaki at 11:00 a.m. on September 4, 1932. T, temperature of water in Centigrade; L.i., light intensity in water; Ep., *Epischura petersi*; Pe., *Polyphemus pediculus*; Bo., *Bosmina longirostris*; Ho., *Holopedium gibberum*; Le., *Leptodora kindti*; Di., *Daphnia longispina*; Cr., *Cyclops crassus*; Cs., *Cyclops strenuus*; Ac., *Acanthocyclops carolinianus* var. *yamanouchi*; Ln., the layer at which the upper margin of the population is found; Lm., the median; Lb., the lower margin.

Depth	T	L.i	Ep.	Pe.	Bo.	Ho.	Le.	Di.	Cr.	Cs.	Ac.
1 m.	25.4	100%	0.33	1.27	0	0	0	0	0	0	0
2	25.2	66	14.7	0.67	3.66	0.33	0	0	1.67	0	1.17
3	23.8	37	0.67	0.87	10.9	1.40	0	0	2.13	0	1.67
4	19.5	16	0.13	1.00	9.00	2.00	0	2.33	1.47	0	7.26
10	12.2	9.9	0	0	9.40	0.07	0.13	9.67	0.33	0.07	9.86
12	—	5.5	0	0	0	0	0	8.00	0	1.07	9.53
15	7.8	2.3	0	0	0	0	0	9.67	0	1.73	2.00
18	—	2.1	0	0	0	0	0	4.00	0	1.60	1.54
20	6.5	1.7	0	0	0	0	0	4.20	0	1.13	0.80
23	—	—	0	0	0	0	0	1.50	0	3.00	0
25	6.6	—	0	0	0	0	0	0.47	0	4.66	0
Ln (m)			1.2	1.1	3.8	2.8	—	11.3	3.5	16.8	8.6
Lm (m)			2.6	3.9	5.7	5.9	19.0	14.2	5.5	22.0	10.7
Lb (m)			3.9	6.6	7.4	7.5	—	17.5	7.2	25.8	12.9

Table XIX. The underwater illumination in Lake Kizaki at 10.45–11.30 A.M. on August 4, 1937. L.a., light intensity from above; L.s., light intensity from side; L.b., light intensity from below. The figures of the second column indicate the value in percentage of the light intensity just below the surface. The figures of the third and fourth columns indicate the value in percentage of the light intensity at the same level from above.

Depth (m)	L. a. (%)	L. s. (%)	L. b. (%)
0.01	100	55	4.8
0.5	88	60	4.9
1.0	79	61	5.0
1.5	72	—	—
2.0	68	60	5.4
3.0	59	47	4.7
4.0	51	45	4.5
5.0	40	46	4.9
6.0	33	52	6.1
7.0	27	52	6.3
8.0	21	57	6.2
9.0	17	65	7.6
10.0	13	70	6.5
11.0	11	71	—
12.0	8.0	71	—
13.0	6.8	59	—
14.0	5.1	51	—
15.0	3.7	62	—
16.0	2.8	61	—
17.0	2.0	50	—
18.0	1.4	50	—
19.0	1.1	50	—
20.0	1.1	50	—
Mean	—	57	5.7

the measurement of the underwater illumination were done by previous methods (KIKUCHI, 1937).

At depths of the lake the daylight is scattered, so that the animals may be illuminated from all directions. The horizontal light intensity is 0.71 to 0.45 of the vertical light intensity, the mean being 0.57. The light travelling upward is 0.047 to 0.085 of that going downward, the mean being 0.057. These facts concur with the observations of POOLE and ATKINS (1929, 1937) who state that in air, under perfectly

uniform sunless sky the ratio between the horizontal and the vertical light will be 0.5, the vertical photometer only receiving light from half a hemisphere, and that the average obliquity of the submarine illumination is about the same as that of diffuse daylight in air. This stands in favour of the view that the phototropism can operate the vertical movement of the plankton animals only on bright day and at the surface layer of the lake where the direction of propagation of light is perceptible, and that at depths where the illumination is diffuse the geotropism may be of great importance for controlling the vertical movement (Clarke, 1934 b).

The values in percentage of the light intensity in water just below the surface reaching 5, 10, 15, and 20 meters are 37, 9.9, 3.3 and 1.7 respectively. The temperature of the surface water is 25.4°C, while below a depth of 5 meters the temperature suddenly falls and is 12.2°C at 10 meters. As is evident from the experimental results the diffrences in the water temperature as well as in the underwater illumination at different depths may exert marked influences upon the vertical movement of the animals.

Dissolved oxygen and hydrogen ion concentration of the water were measured but no connection with the vertical distribution of the plankton animals was altogether detected in Lake Kizaki.

V. Discussion

Not only does the vertical movement of plankton crustaceans vary in different species and lakes, but also it is quite dependent of several causes. Glancing over the interpretations previously set forth concerning this respect there can be distinguished the following causes. (1) The reversal of the phototropic sign with changes of the light intensity is pointed out by Groom and Loeb (1908) in nauplii of *Balanus*; Parker (1901) in *Labidocera aestiva*; Rose (1925) in *Daphnia longispina* and some marine copepods; and Clarke (1930) in *Daphnia magna*. (2) The reversal of phototropic sign with changes in the water temperature is shown by Loeb (1893) in *Daphnia pulex, Polygordius* larvae, and *Temora longicornis*; Esterly (1919) in *Acartia tonsa, A. clausi, Calanus finmarchicus*, and *Metridia lucens*; and Rose (1925) in *Daphnia longispina* and some marine copepods. (3) The reversal of geotropic sign induced by changes of the light intensity is pointed out by Esterly (1907, 1912, 1919) in *Cyclops albidus, Acartia tonsa, Labidocera aestiva*, and *Sagitta bipunctata*; Harper (1907) in

Corethra larvae; McGinnis (1911) in *Branchipus serrutus*; Dice (1914) in *Daphnia pulex*; and Fox (1925) in *Paramecium* and *Diadema* larvae. (4) The reversal of geotropic sign induced by changes of the water temperature is indicated by Parker (1901) in *Labidocera aestiva*; Dice (1914) in *Daphnia pulex*; and Esterly (1919) in *Acartia tonsa, Metridia lucens,* and *Calanus finmarchicus*. (5) The physiological rhythm of the animals in connection with the phototropism or the geotropism is shown by Loeb (1914) in some marine copepods; Esterly (1919) in *Acartia tonsa, A. clausi,* and *Calanus finmarchicus*; and Eyden (1925) in *Daphnia pulex*. (6) The speed and duration of the swimming movement is detected by Clarke (1934 a) in *Calanus finmarchicus*; and Kikuchi (1937) in some forms of Cladocera. (7) The turbulence due to the wave action may be in some cases of great importance (Ruttner, 1914), but this is ordinarily of negligible effect for such strong swimmers as plankton crustaceans (Clarke, 1934 b). (8) Such dissolved gases as oxygen, hydrogen sulfide, and carbon dioxide restrict in some cases the lower limit of the vertical distribution of the plankton animals (Loeb, 1909; Ruttner, 1914; Kikuchi, 1930).

Now let us pass on to a consideration of the possible bearings of the present experiments upon the vertical distribution of the plankton crustaceans observed in Lake Kizaki (Kikuchi, 1927, 1930, 1937), dividing into three categories.

(1) In such species as *Bosminopsis deitersi, Polyphemus pediculus, Holopedium gibberum, Diaphanosoma brachyurum,* and *Leptodora kindtii,* the diurnal change in the vertical distribution might be divided, according to my previous observations (Kikuchi, 1930), into four types as follow: In the first type the animals actually congregate near the surface at night, leaving the deeper strata. In the second type they merely move about at night up to the surface layer where they vacate during the daytime, and as a result they are more or less uniformly distributed. In the third type they show a slight tendency toward the upward migration at night but only a few individuals or none ascend up to the surface. In the fourth type the animals come up to the surface twice at dusk and dawn, and swim down to the deeper strata at night. The first, second, and third types are called by Ruttner (1905) "nocturnal migration" and the fourth type "twilight migration."

From laboratory experiments we know that *Leptodora* swims upward to light as fast as 51 cm/min, *Holopedium* 25 cm/min, *Bosminopsis*

22 cm/min, *Polyphemus* 23 cm/min, *Daphnia* 86 cm/min, and *Acanthodiaptomus* 62 cm/min. If such speed can be maintained for a considerable period of time in nature and the range of the vertical movement is confined to depths of 5–10 meters as in Lake Kizaki, it would appear that the time required for changing the vertical distribution of the animals is in fact left out of consideration. But for the animals which move upward in the evening more than 100 meters (Clarke, 1934 a) the speed and the duration of the swimming movement serve as some important factors controlling the vertical distribution of the plankton.

During the daytime *Bosminopsis* and *Polyphemus* may be distributed at a level where the light intensity is so strong that the negative phototropism is induced because they become phototropic positively to weak light and negatively to stronger light. The geotropic response does not take a rôle in the vertical movement of those forms. In *Holopedium, Leptodora,* and *Diaphanosoma,* however, the phototropic and geotropic forces are directly antagonized during the daytime. When the light intensity is suddenly decreased or the animals swim down to the deeper strata, the phototropic force becomes stronger than the geotropic force; consequently the animals show a tendency toward the upward movement which ceases when they reach the upper layer where the light intensity is strong. As the results the animals will repeat the downward and upward movements at a level where the phototropic and geotropic forces are balanced. The observational data show that *Bosminopsis* and *Polyphemus* are distributed at upper levels than *Holopedium, Diaphanosoma,* and *Leptodora,* while the latter three forms show a stronger tendency toward the positive phototropism than the former two, and further that *Polyphemus* and *Bosminopsis* change their vertical distribution in wide range during the course of a day, while *Diaphanosoma* and *Holopedium* are located at about the same level.

Some observations (Worthington, 1931; Southern and Gardiner, 1932; Harada, 1934; Clarke, 1934 a; Kikuchi, 1937) indicate that the plankton crustaceans show a tendency to the upward migration at midday, contrary to the increase in the intensity of the sunlight. This appears in all probability to be due to the light adaptation of the animals.

A marked tendency toward the upward movement in the evening may be readily accounted for by the positive phototropism of animals

to weak intensity of light. If the animals are located very near the surface during the daytime, it might be expected that they actually accumulate near the surface at dusk (the fourth type). In *Bosminopsis* whose secondary phototropic sign is temporarily positive, the animal comes up to the surface following a reduction of the light intensity. For example, the observations made on August 6, 1929, in Lake Kizaki show that *Bosminopsis* comes up to the surface twice at dusk, at 5.30 P.M. when the sun sinks below the mountains and at 7.30 P.M., after the true sunset. For the animals living in deeper strata during the daytime, it might be expected that they perform migrations of the first and second types. But for the animals living in or below the metalimnion during the daytime and showing the positive geotropism in changing the water temperature, the third type will be performed. For example, on August 20, 1927, in Lake Aoki and on August 6, 1929, in Lake Kizaki, *Holopedium* was located below a depth of 8 meters during the daytime and none came up to the surface at night, while on August 12, 1925, and July 26, 1927, in Lake Kizaki the same animal was located below a depth of 2 meters during the daytime and appeared at the surface at dusk.

Needless to say, the cause of the migration at night is attributed to the geotropism but not to the phototropism. *Polyphemus* and *Bosminopsis* show a slight tendency to the downward movement (the fourth type), because they are indifferent or positive to gravity in darkness. *Diaphanosoma* and *Holopedium* are neutral or positive to gravity in darkness; consequently it might be expected that the upward migration is accomplished during the period of very dim light at dusk. Contrary to these facts the accumulation of those forms at the surface of the lake is found to be greatest in early hours of night. The problem deserves further investigation.

At dawn the animals show a tendency to the upward migration. Especially it is evidently demonstrated in *Polyphemus* and *Bosminopsis* which are positively phototropic to such weak intensity of light and indifferent to gravity (the fourth type). In *Holopedium* and *Diaphanosoma* which are positively geotropic in light the ascent is hardly observed (the first and second types). The downward movement after the sunrise is due to the negative phototropism and positive geotropism which are produced by the increase of the light intensity.

(2) As regards *Acanthodiaptomus pacificus* var. *yamanacensis*. At dawn the animal leaves the surface and sinks downward to the

hypolimnion, because it becomes in diffuse light positively geotropic when brought from darkness, and also it becomes positively geotropic when the water temperature is suddenly changed in light.

During the daytime the animal is distributed in the meta- and hypolimnion at any intensity of light, because the positive geotropic force overcomes the positive phototropic force when it moves up to the metalimnion where the water temperature suddenly changes. For example, the vertical distribution of this species in the lakes of Kizaki, Aoki, Nisi, and Motosu shows that the upper limits of the vertical distribution are found in the metalimnion and that the light intensities at the upper limits range from 0.67 to 21 (in relative intensity). It might be also expected that in lakes where the water temperature is uniform from the surface to the deep strata, such as Lake Kizaki in Autumn as well as some lakes in Nikkô, Hokkaidô, and the Kuriles, this species is uniformly distributed in the surface layer during the daytime, because it is indifferent to gravity and positively phototropic.

At night the animal comes up to the surface one hour after the sunset and the accumulation is greatest at 8–10 P.M. because it becomes negatively geotropic or neutral to gravity when placed in darkness from light, and also is regains the original positive sign after being kept in darkness for two hours or more.

(3) *Daphnia longispina* is distributed in or below the metalimnion throughout the day and night and never comes up to the epilimnion. This state of things would be explained from the facts that both in light and darkness the animal becomes temporarily positively geotropic with changes in the water temperature. It appears to be also due to the temporary negative phototropism induced by the increase of the light intensity and water temperature when the animal swims up to the upper layer.

VI. Summary

1. *Polyphemus pediculus* is phototropic positively to weak light but negatively to strong light. In diffuse light it is indifferent or positive to gravity but shows a marked tendency toward the positive geotropism in darkness.

2. *Bosminopsis deitersi* is negatively phototropic to very strong light but is indifferent to weak intensity of light. A sudden decrease of the light intensity results in the temporary positive phototropism, while a sudden increase gives the negative phototropism. This species

is indifferent to gravity both in light and darkness at any temperature.

3. *Holopedium gibberum, Leptodora kindtii,* and *Diaphanosoma brachyurum* are positively phototropic but become temporarily negatively phototropic when the light intensity is suddenly increased. These animals are positively geotropic in diffuse light at any temperature. In darkness they are indifferent to gravity but show temporarily a slight tendency to the positive geotropism when the water temperature is raised.

4. In *Daphnia longispina* the primary phototropic sign is neutral but the temporary negative phototropism is induced when the light intensity is suddenly increased or the water temperature is changed, while the reverse change of the phototropism occurs when the light intensity is suddenly decreased. In diffuse light this species is indifferent to gravity, but changes in the water temperature produce temporarily the positive geotropism. In darkness it is indifferent to gravity or shows a slight tendency to the positive geotropism under uniform conditions, while changes in the water temperature cause an increase of a tendency to the positive geotropism.

5. *Acanthodiaptomus pacificus* var. *yamanacensis* is positively phototropic to any intensity of light at any temperature. In diffuse light this species is indifferent or positive to gravity under uniform conditions. Sudden changes in the light intensity and water temperature cause a tendency to the increase of its positive geotropism. In darkness the animal is indifferent or positive to gravity at any temperature, and any sign of change in the geotropic response does not occur when the water temperature is suddenly changed.

6. The diurnal vertical migration of plankton crustaceans in the lake is generally explained from the reversal of the phototropic and geotropic signs of animals induced by changes in the light intensity and water temperature.

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Studies of the Bottom Material of Simoda Bay, Idu Peninsula*

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With 14 Text-figures

1. Introduction

Scope of the Study. The writer has been investigating to find a reliable method for identifying the raised beach deposits, which consist of, besides beach gravels and fossils, sand, mud, and clay as marine deposits on the terrace surface. As the first step the writer examined the nature and characteristics of the bottom material of Simoda bay, Sizuoka prefecture, Japan, with the object of obtaining some idea of the marine deposits of a bay into which a river drains, and to ascertain the monthly variations in the character of these deposits.

In this paper the results of investigations are described, with the view that it is one of the fundamental studies concerning the problem of raised beach deposits. In due course the writer expects to apply the presently obtained results to the sands found on the coastal terraces in the province of Tosa, Japan.

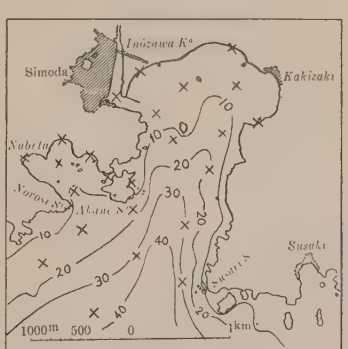

Fig. 1. Submarine topography of Simoda Bay (depth in metres), and the localities where the bottom samples were dredged.

Bottom Sampler and Mechanical Analysis. Bottom material was taken from 25 places (Fig. 1) by means of a new bottom sampler, namely, an iron tube about 30 cm long and 7 cm in diameter. The bulk density [ρ] in a

* Contribution from the Simoda Marine Biological Station, Tokyo Bunrika Daigaku, No. 30.

dry condition was determined by a centrifuge, whereas the grain density $\bar{\rho}$ was measured by means of an ordinary picnometer. The sizes of the sand particles were measured by standard sieves, the meshes of which are 0.25 mm, 0.50 mm, 1.0 mm, and 2.0 mm, the material being separated into four classes—large, medium, small, and fine. The particles remaining on the 2.0 mm screen are regarded rather as pebbles.

2. Density

Bulk Density $[\rho]$. Fig. 2 (a~l) shows the annual variation in the distribution of $[\rho]$ in Simoda bay. One of the most remarkable characteristics is that the sands near the beach show larger values of $[\rho]$, while those in the central part of the bay have smaller values, and at the river-mouth a slightly larger density during the rainy seasons (IX, X etc.) and somewhat smaller values during the dry seasons (XI, II etc.). Along the eastern and western coasts, where new sand is being formed by wave action at the foot of the sea cliffs, the value of $[\rho]$ is great throughout the year. On the other hand, along the northern coast, where no new sand is being formed, the value of $[\rho]$ reaches the minimum in January (1937), owing to the lighter particles from the central area of the bay being carried shoreward. This current is caused by the prevailing western wind (10~20 m/sec). The small value of $[\rho]$ along the northern coast, was not observed after March.

Grain Density $\bar{\rho}$. Fig. 3(a~l) shows the annual variation in the distribution of $\bar{\rho}$ in Simoda bay. On examining this figure, it will readily be noticed that the fluctuations or seasonal changes in Simoda bay are much more marked than that of $[\rho]$. $\bar{\rho}$ is very susceptive to circulation and movement of sea water. A careful inspection of Fig. 3 (a~l) will show that similar conditions recur every 2 or 3 months, which is unfavourable for determining the position of the old shoreline or for correlating the various raised beaches, it being better suited for studying the temporal condition of the bay.

Moreover, Figs. 2, 3 show that river influence has been quite insignificant as an agent in the sedimentation of a bay.

3. Size-grade

The accompanying figures (4, 5, 6, 7) give results of the mechanical analysis of sand made for a period of a year in the form of percentage distribution of the grain size noted on a map of Simoda bay.

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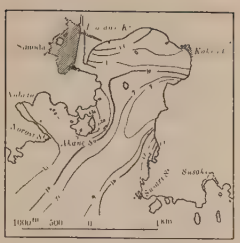

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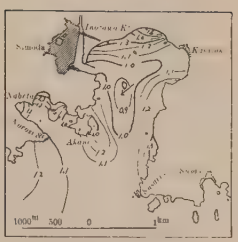

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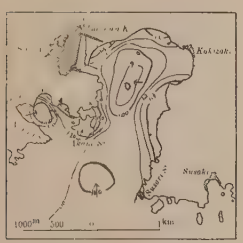
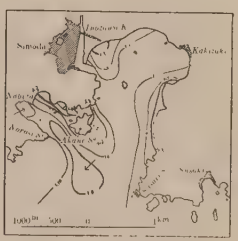


d (Dec. 1936)

e (Jan. 1937)



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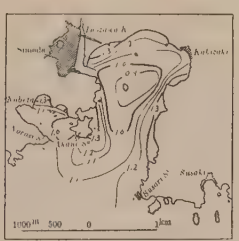

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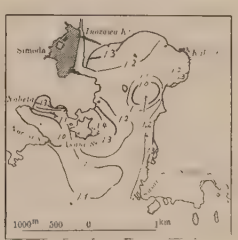

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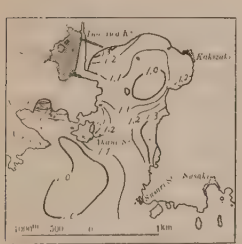

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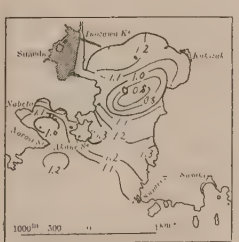

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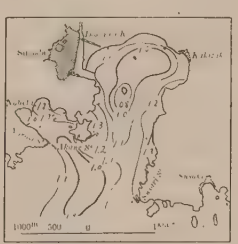
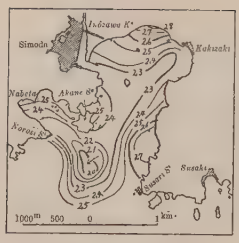


l (Aug. 1937)

Fig. 2. Monthly variations in the bulk density [ρ] in Simoda Bay (1936–1937)



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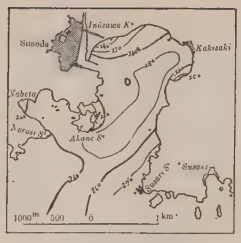

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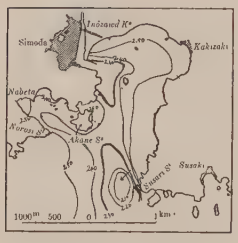

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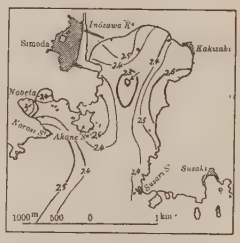

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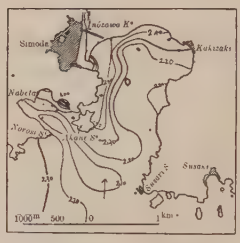

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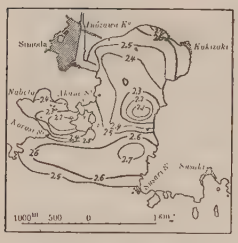

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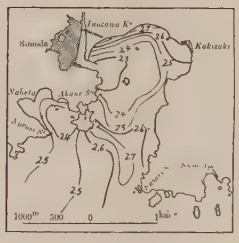

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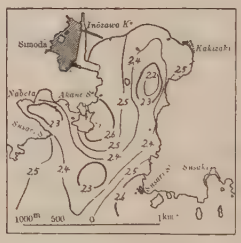

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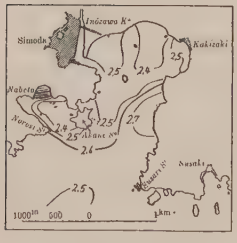

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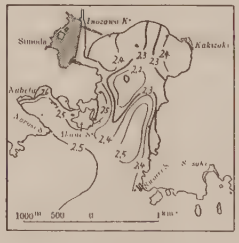

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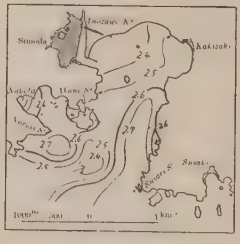


l (Aug. 1937)

Fig. 3. Monthly variations in the grain density $\bar{\rho}$ in Simoda Bay (1936–1937)

The writer has noticed that freshly crushed sand from a sea cliff is very coarse and angular, and of large size, with the result that the largest sand particles are distributed along the rocky strand where it was worn down from the mother rock by the grinding action of the sea waves. The annual variation in distribution of the large sand particles is shown in Fig. 4 (a~1), in which no marked change is noticed for the period from September 1936 to January 1937, whereas the effect of the prevailing wind shows itself from February.

The medium sized sand particles (Fig. 5) come from two sources, the river and the sea (rocky strands in the bay and from outside the bay). In Simoda bay, however, the sand from the river is quite negligible, except during the rainy months (IX, X, etc.), while the sand from the sea is abundant, especially in winter, owing to the violent erosion and transportation by means of wave and wind. In the distribution of this sand, the percentage is highest along the rocky strands of the eastern and western coasts, with a moderate quantity at the bay entrance, as also on the northern beach.

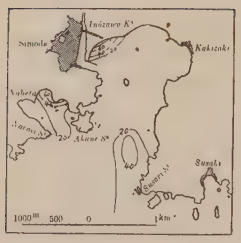
Since small sand particles (Fig. 6) settle down only in calm water, their prevalent distribution is expected only in the recesses of bays. Actually, we find it not only in the northeastern recess, but also in the western side, outside the bay, the reason for which will be explained later in the conclusion. This sand is found in every part of the bay (sand beaches, rocky strands, recesses, the bay mouth, and outside the bay) though with wide divergences in percentage, for which reason the writer expects this sort of sand will be of help in determining the past condition of sedimentation on an upheaved marine terrace.

Fine sand (Fig. 7), which is readily transported from its original source, settles down in the most undisturbed parts of the bay, for example, in the recesses, the center, and the outside of the bay. As a matter of fact some fine sand comes from the river, but their complete sedimentation is controlled by the sea water, which fact will be seen from a careful inspection of the distribution map of this sand (Fig. 7).

The area in which we find this size, extends from the western part of the bay to the eastern part of the bay recess—a result of the drift current caused by the prevailing western winds.

4. Currents in Simoda Bay

As to the circulation of the surface water, no direct measurements have yet been made in Simoda bay, although a number of oceanic



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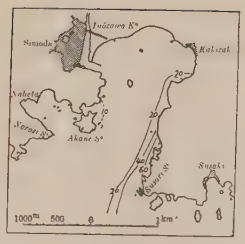

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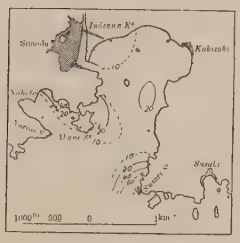

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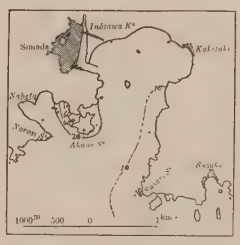

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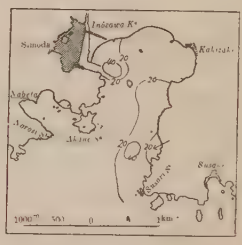

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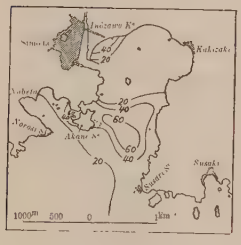

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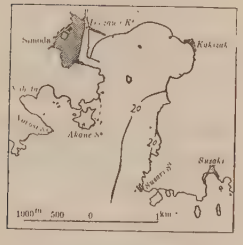

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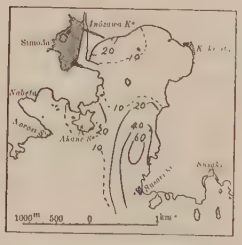

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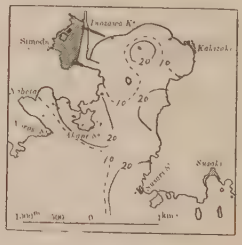
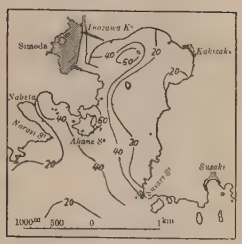


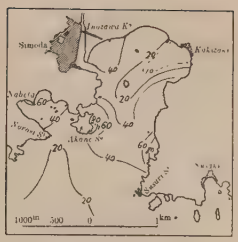
l (Aug. 1937)

Fig. 4. Monthly variations in the percentage of sand grains 2.0 mm–1.0 mm (1936–1937)

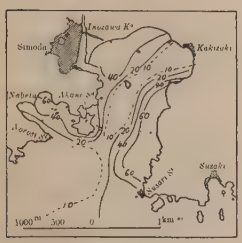
a (Sept. 1936)



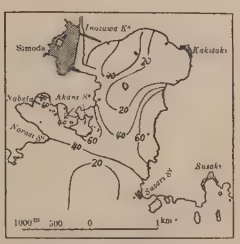
b (Oct. 1936)



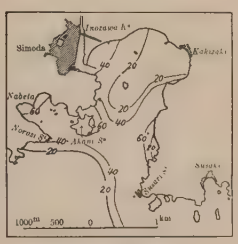
c (Nov. 1936)



d (Dec. 1936)



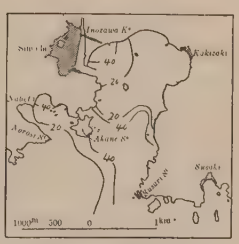
e (Jan. 1937)



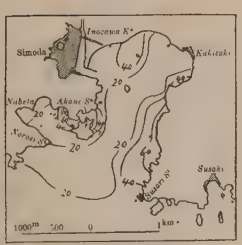
f (Feb. 1937)

g (Mar. 1937)

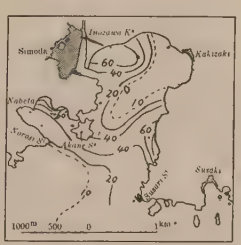
h (Apr. 1937)



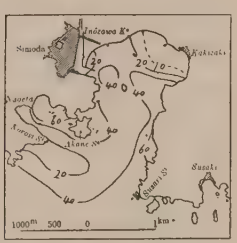
i (May 1937)



j (June 1937)



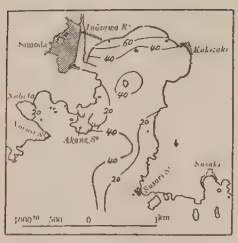
k (July 1937)



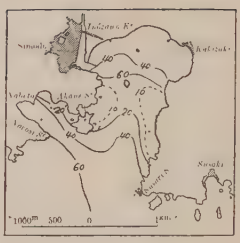
l (Aug. 1937)

Fig. 5. Monthly variations in the percentage of sand grains 1.0 mm–0.5 mm (1936–1937)

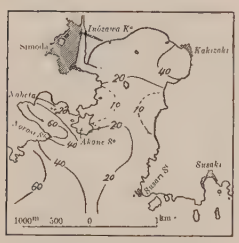
a (Sept. 1936)



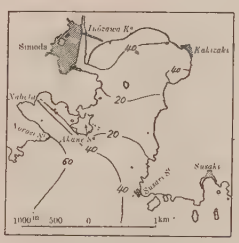
b (Oct. 1936)



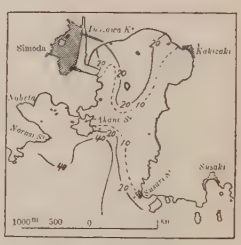
c (Nov. 1936)



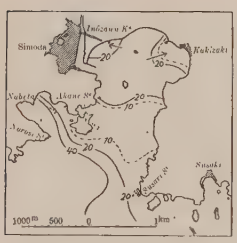
d (Dec. 1936)



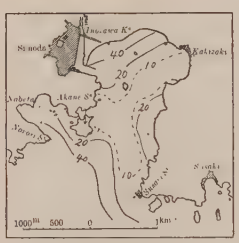
e (Jan. 1937)



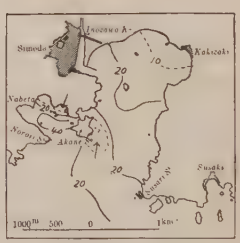
f (Feb. 1937)



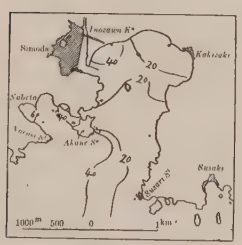
g (Mar. 1937)



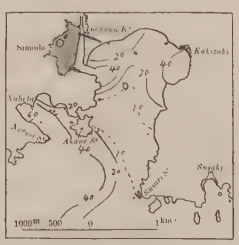
h (Apr. 1937)



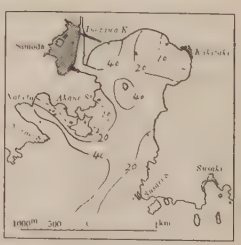
i (May 1937)



j (June 1937)

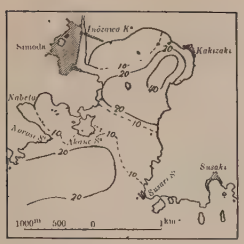


k (July 1937)

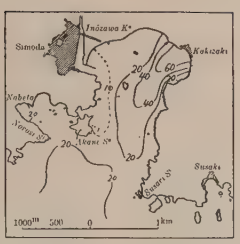


l (Aug. 1937)

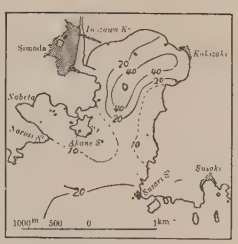
Fig. 6. Monthly variations in the percentage of sand grains 0.5 mm–0.25 mm (1936–1937)



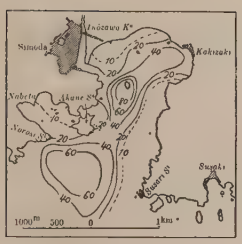
a (Sept. 1936)



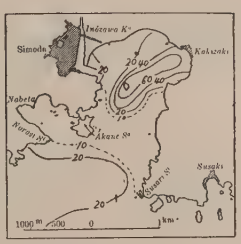
b (Oct. 1936)



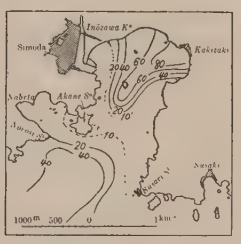
c (Nov. 1936)



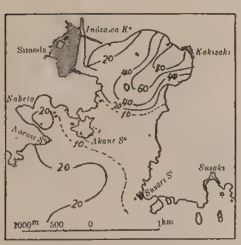
d (Dec. 1936)



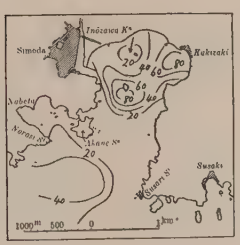
e (Jan. 1937)



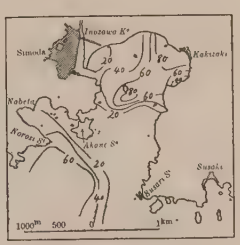
f (Feb. 1937)



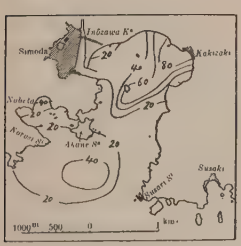
g (Mar. 1937)



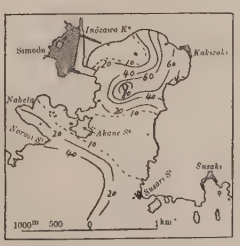
h (Apr. 1937)



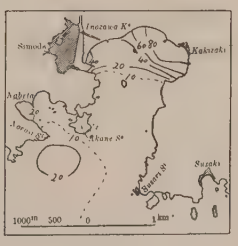
i (May 1937)



j (June 1937)



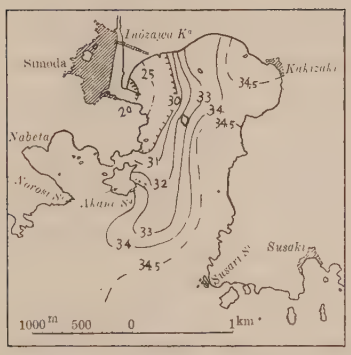
k (July 1937)



l (Aug. 1937)

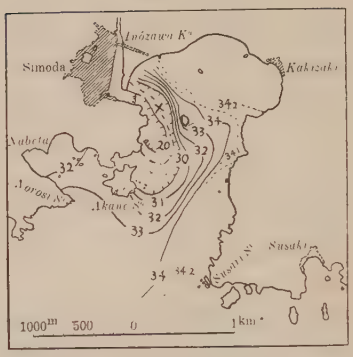
Fig. 7. Monthly variations in the percentage of sand grains<0.25 mm (1936–1937)

Fig. 8–1.



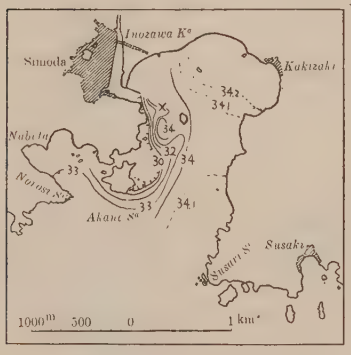
S‰ 23rd Feb., 1937 (0^m layer)

Fig. 8–2.



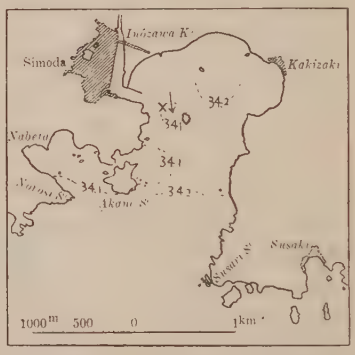
S‰ 29th June 1937 (0^m layer)

Fig. 8–3.



S‰ 29th June 1937 (1^m layer)

Fig. 8–4.



S‰ 29th June 1937 (5^m layer)

Fig. 8. Salinity distribution in Simoda Bay (× indicates the spot where the current was measured)

observations have been carried out, the reports of which have already been published,[1] with some now in press. The water temperature, pH, and the salinity of the surface water were tested. According to the circulation of the surface water we know that the oceanic water enters the bay from along the eastern coast, while the fresh water from the Inôzawa river flows out of the bay hugging the western strand when conditions in the bay are normal (Fig. $8{\cdot}_1$, $8{\cdot}_2$). In order to examine the submarine current, a special survey was conducted in Simoda bay on June 29, 1937: the salinity at 1.0 m and 5.0 m below

1) S. Yoshimura: Oceanographical Observations of Simoda Bay, Idu Peninsula. Sci. Rep. Tokyo Bunrika Daigaku, Sec. C, No. 3, 1936.

the surface being shown in Fig. 8·3, 8·4. Since there is no difference in salinity between the eastern and western parts of the bay in the water layer 5.0 m below the surface, this layer retains its pure oceanic character. Even immediately below the surface, the effect of the fresh water is not very obvious.

The directions of the currents at various depths are all to the southwest, as shown in the plane figure (9), which gives these directions for the various depths as measured from the northwestern corner of the bay. It follows therefore that the oceanic water with its high salinity enters the bay through the eastern part of its mouth, turns to the west at the recess, and goes out along the west coast, carrying with it the fresh river water on its surface. The velocity of the current at each depth has been surveyed only once, with an Ekmann-Merz current-meter, at the north-western corner of the bay. For convenience in comparing each layer, the measured value has been noted in the graph, Fig. 9. The velocity of the surface layer (54.4 cm/minute) is about three times that at a depth of 1.0 m, which is probably the effect of the driving wind. It must be remembered that at this part of the bay, a southwestern stream runs with almost equal velocity through the thick layer from the bottom up to a depth of 1.0 m below the surface. That is to say, notwithstanding the temporal decrease in the velocity of the current to as low a speed as 10 cm per minute 5.0 m below the surface, the velocity has again increased, amounting to 15.4 cm per minute at a depth of 10.0 m and 14.5 cm per minute near the bottom (13.5 m). The energy of this velocity near the bottom gives rise to eddies in the water layer adjacent to the sea bed, with the result that the bottom materials, such as sand and even small pebbles, are carried away by these eddies.

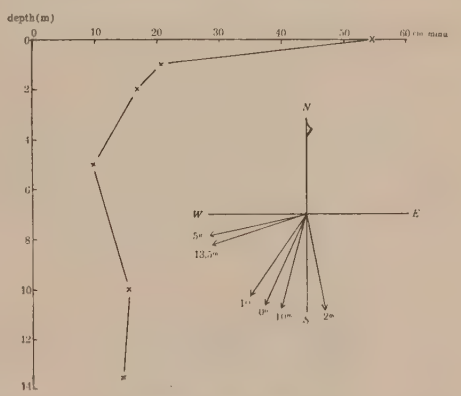


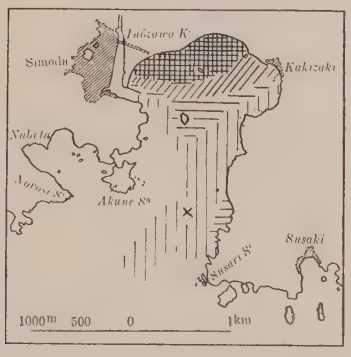
Fig. 9. Direction and velocity of the tidal current at NW corner of Simoda Bay (marked × in Fig. 8), June 29, 1937, in the forenoon.

5. Transportation of Bottom Material

An experiment was made on February 15, 1937, with the object of ascertaining the facts relating to the circulation of the bottom material that is transported by the eddies due to the action of the current adjacent to the sea bed. The experiment as undertaken in collaboration with Professor G. Imamura, consisted in sinking powdered brick in the eastern part of the bay entrance, to a depth of 47 m, with as little shaking as possible. Later, samples of sand were collected on two occasions at the same twenty five places in the bay, namely, on February 27 (12 days later) and on March 23 (36 days later). One gram of each sample was examined with a microscope, and the brick particle content of the hauls classified as follows:

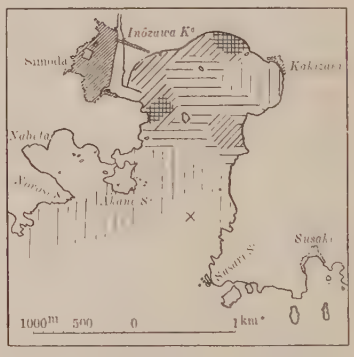
0—none 5—small quantity 10—medium quantity
15—large quantity 20—very large quantity.

Two maps (Fig. 10, a and b) show the results of the calculated contents of the brick particles mentioned above. Fig. 10, a, shows that the brick particles that were sunk at the bay entrance 12 days before, have shifted to a great distance in the northern part of the bay via the northeastern corner (Kakisaki) and accumulated near the river



4 very large quantity
3 large quantity
2 medium quantity
1 small quantity
0 none

a) 12 days after throwing
(27th Feb., 1937)

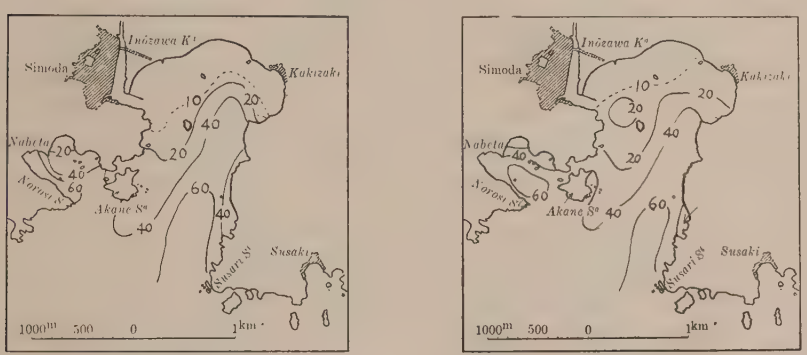


b) 36 days after throwing
(23rd Mar., 1937)

Fig. 10. Transportation of brick dust by bottom currents. × shows the spot where the dust was allowed to be sunk.

mouth—a very quick movement considering the short time involved. Fig. 10, b, indicates that the brick particles which occupied the northern recess of the bay, as shown in Fig. 10, a, moved southward, while some of it moved out of the bay, westward, although most of it seemed to remain in the bay. This experiment proved that the sand on the bottom is transported in a counter-clockwise direction.

Shell content. The shell content of the marine sand was arrived at by determining the loss in weight, after hydrochloric acid (3.8%) was poured into a certain quantity of the material. This value was plotted in maps for the period of a year; all the figures, however, being more or less similar, only two that are representative have been inserted in Fig. 11. It may be pointed out that the shells do not advance into



Jan. 1937 July 1937

Fig. 11. Percentage of shells found in the bottom samples.

the inner bay, the tendency being to advance along the eastern part (48 m. deep) of the bay entrance, with traces of its having withdrawn from the western part. This phenomenon also indicates the existence of a counter-clockwise circulation of the bottom current. It is supposed that there is a large accumulation of shells on the sea floor outside the bay, the sizes of their particles together with the angularities preventing them from being carried into the bay. If the velocity of the bottom current were slightly faster, or the depth at the entrance of the bay as shallow as 10 m, so as to enable the wind to affect the drift current, the shells outside the bay would have been carried into it and stranded on the northern beach, as is actually the case in Sotoura bay, 3 km east of Simoda.

6. Oscillation of Bottom Material with Large Period

As the time-variation of $\bar{\rho}$ at each place was too large to be attributed to observational error, a route was selected as shown in Fig. 12. Plotting the positions of the sample-collecting stations as abscissae, the writer treated the value of increase and decrease during one month (for example Oct.–Nov.) as ordinates using the sign (+) and (−) (Fig. 13). From this figure, the important conclusion is drawn that, in course of time, the increase and decrease alternate like a train of waves, moving from left to right in a fairly regular manner. The relation between the lapse of time and the travel of the wave crests as determined from Fig. 12 are shown in Fig. 14, the months being abscissae and the distance along the route the ordinates, as in Fig. 12. It may be worth noting that seven waves have passed along this route during

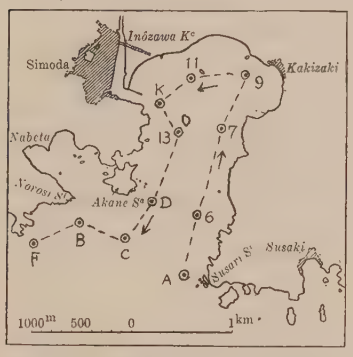


Fig. 12. Supposed route of sand transportation.

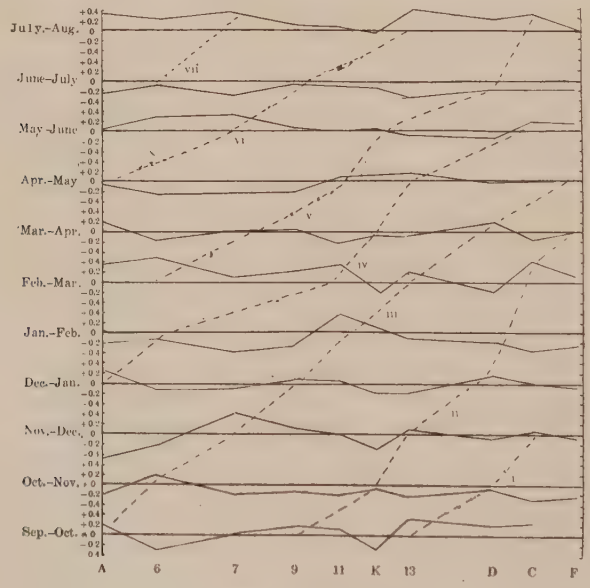


Fig. 13. Monthly increase and decrease in the values of $\bar{\rho}$ along the route shown in Fig. 12.

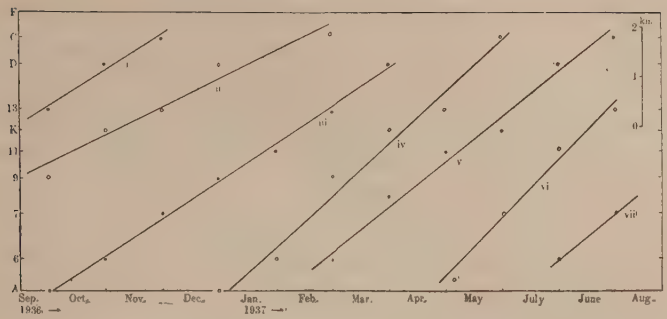


Fig. 14. Long-periodic fluctuations of $\bar{\rho}$. Ordinate gives the stations along the route shown in Fig. 12, scale being on the right hand side of the figure.

one year (from September 1936 to August 1937). These waves appear as seven oblique lines in Fig. 14. Calculating the mean value of the elements of the wave undulations, the writer obtained the following:

Period .....2 months
Wave-length .....1.5~2.0 km.
Velocity .....1 m/hour (2 cm/minute).

To prove this undulation, which was found by measuring $\bar{\rho}$, the writer examined the samples again very carefully. When $\bar{\rho}$ reached the maximum (for example, $\bar{\rho}$=3.00, St. 10, November, 1936), it was ascertained that a large quantity of *magnetite* dust was included in the material rendering the colour quite black. Magnetite was found to be the main cause of this undulation. Although the specific gravity of magnetite is high, the grains were so small that they could easily be carried along the bottom of the bay, their movement being in a counter-clockwise direction. As to the mechanism of this periodic oscillation of magnetite dust in the bay, however, nothing in the way of explanation or experiment has yet been attempted.

7. Conclusions

This investigation has disclosed the process in which the natural sorting of bottom material is done in a bay, where a rotatory current exists in each layer from the bottom up to the surface. Attention is called to the fact that the size of the particles of the bottom material is of supreme importance in the actual sorting out in the sea. Inspection of a map of the size-particles of any month taken at random, say

July 1937, will show that sands of large size generally stay outside the bay and seldom enter it, while those of the finest size reach the remote recess of the bay, a part of it flowing out, depositing on the western side, outside the bay. Regardless of its high specific gravity, owing to its small size, particles of magnetite have circulated over the bay bottom. On the other hand, shells with small $\bar{\rho}$ can not enter the bay owing to their large size. The greater the velocity of the bottom current, the greater the ease with which the large particles of sand are carried into a bay, by which we can recognize the individual character of each bay.

The size of the particles composing the sediment of the bay shows marked variation along the margin of the bay, as well as in specific gravity, shape, and mineral composition, more so than in the interior of the bay. This is the effect of wind and wave action, which directly attack and decompose the rock on the sea-shore, as the writer has pointed out in the preceding sections. These détritus are transported to the sandy beach by the littoral current from rocky cliffs: this is attested by the fact that in the margin may be seen a high content of medium sized sand, which is akin to the increases in $[\rho]$ near the shore; $[\rho]$ corresponding to the mean diameter of the sampling sands.

Lastly we shall examine the origin of the bottom material. It is clear that the quantity that the ocean brings into Simoda bay exceeds by far that which the Inôzawa river pours into it. Moreover, the quantity of water in the river is a function of the rainfall, especially during winter when the river bed becomes quite dry. Even after a heavy rain, the fresh water that covers the bay is only superficial, with the result that the détritus carried by the river are at the mercy of the oceanic water soon after it enters the bay, so that sedimentation must occur according to the condition and the movement of the sea water. For these reasons, the conception of a cycle of sedimentation as being due to the effect of rivers should be entirely eliminated in explaining the accumulation of détritus in a bay.

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Classified List of Papers and Reports Bearing on Oceanography Published in Japan during 1937, with supplement

(* articles written in Japanese)
(§ articles with resume in foreign language)

Abbreviations

Ann. Zool. Jap. .....Annotations Zoologicae Japonenses, Tokyo.

Bot. and Zool., Tokyo .....Botany and Zoology (Magazine), Tokyo.

Bull. Biogeogr. Soc. Japan. .....Bulletin of the Biogeographical Society of Japan, Tokyo.

Bull. Earthq. .....Bulletin of the Earthquake Research Institute, Tokyo Imperial University, Tokyo.

Bull. Jap. Soc. Sci. Fish. .....Bulletin of the Japanese Society of Scientific Fisheries, Tokyo.

Chikyû .....The Globe, Kyoto Imperial University (now out of print), Kyoto.

Ecol. Rev. .....Ecological Review, Tôhoku Imperial University, Sendai.

Geogr. Rev. Jap. .....Geographical Review of Japan, Tokyo.

Hokkaidô Fish. Exp. Sta. .....Hokkaidô Fisheries Experimental Station, Hokkaidô.

Hukuoka Hak-G. Z. .....Hukuoka Hakubutugaku Zassi (Hukuoka Journal of Natural History), Kyûsyû.

Hyd. Bull. .....Hydrographical Bulletin (Suirô Yôho).

Jap. Jour. Astron. Geophys. .....Japanese Journal of Astronomy and Geophysics, Tokyo.

Jap. Jour. Geol. Geogr. .....Japanese Journal of Geology and Geography, Tokyo.

Jap. Jour. Limn. .....Japanese Journal of Limnology, Tokyo.

Jour. Fish. Culture, Tokyo .....Journal of Fish Culture, Tokyo.

Jour. Met. Soc. Tokyo .....Journal of the Meteorological Society of Japan (Kisyô Syûsei), Tokyo.

Jour. Jap. Soc. N. A. .....Journal of the Japanese Society of Naval Architecture, Tokyo.

Jour. Ocean. .....Journal of Oceanography (Kaiyô Zihô).

Jap. Jour. Zool. .....Japanese Journal of Zoology, Tokyo.

Jour. Fac. Sci. Hokkaidô Imp. Univ. .Journal of the Faculty of Science, Hokkaidô Imperial University, Hokkaidô.

Jour. Geogr.	Journal of Geography, Tokyo.
Jour. Geol. Soc. Jap.	Journal of the Geological Society of Japan, Tokyo.
Mem. Coll. Sci. Kyoto Imp. Univ.	Memoirs of the College of Science, Kyoto Imperial University, Kyoto.
Mem. Marine Obs.	Memoirs of the Imperial Marine Observatory, Kobe.
Proc. Imp. Acad.	Proceedings of the Imperial Academy, Tokyo.
Palao Trop. Biol. Sta. Studies	Palao Tropical Biological Station Studies, Palao, South Sea Islands (Published in Tokyo).
Rec. Ocean. Wk. Jap.	Records of Oceanographic Works in Japan, Tokyo.
Saito Ho-on Kai Mus., Res. Bull.	Saito Ho-on Kai Museum, Research Bulletin, Sendai.
Sci. Rep. Tôhoku Imp. Univ., Ser. 2.	Science Reports of the Tôhoku Imperial University, Series 2, Geology, Sendai.
Sci. Rep. Tôhoku Imp. Univ., Ser. 4.	Science Reports of the Tôhoku Imperial University, Series 4, Biology, Sendai.
Sci. Rep. Bunrika Daig.	Science Reports of the Tokyo Bunrika Daigaku (College of Science and Literature, Tokyo.
Trans. Pal. Soc. Jap.	Transactions of the Palaeontological Society of Japan, Tokyo.
Trans. Sapporo Nat. Hist. Soc.	Transactions of the Sapporo Natural History Society, Sapporo.
Tyôsen Nat. Hist. Soc.	Tyôsen Natural History Society, Tyôsen.
Umi to Sora	Umi to Sora (Sky and Water).
Venus	The Malacological Society of Japan, Kyoto Imperial University, Kyoto.
Zool. Mag.	Zoological Magazine (Formerly Dobutugaku Zassi), Tokyo.

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